TECHNICAL SPECIFICATION

DESIGN OF CATHODIC PROTECTION SYSTEMS FOR NEW FIXED OFFSHORE STEEL STRUCTURES
(AMENDMENTS/SUPPLEMENTS TO DNV RP B401)

DEP 37.19.30.30-Gen.

December 1995

DESIGN AND ENGINEERING PRACTICE

USED BY

COMPANIES OF THE ROYAL DUTCH/SHELL GROUP

PREFACE

DEP (Design and Engineering Practice) publications reflect the views, at the time of publication, of:

Shell International Oil Products B.V. (SIOP)
and
Shell International Exploration and Production B.V. (SIEP)
and
Shell International Chemicals B.V. (SIC)

The Hague, The Netherlands,

and other Service Companies.

They are based on the experience acquired during their involvement with the design, construction, operation and maintenance of processing units and facilities, and they are supplemented with the experience of Group Operating companies. Where appropriate they are based on, or reference is made to, national and international standards and codes of practice.

The objective is to set the recommended standard for good design and engineering practice applied by Group companies operating an oil refinery, gas handling installation, chemical plant, oil and gas production facility, or any other such facility, and thereby to achieve maximum technical and economic benefit from standardization.

The information set forth in these publications is provided to users for their consideration and decision to implement. This is of particular importance where DEPs may not cover every requirement or diversity of condition at each locality. The system of DEPs is expected to be sufficiently flexible to allow individual operating companies to adapt the information set forth in DEPs to their own environment and requirements.

When Contractors or Manufacturers/Suppliers use DEPs they shall be solely responsible for the quality of work and the attainment of the required design and engineering standards. In particular, for those requirements not specifically covered, the Principal will expect them to follow those design and engineering practices which will achieve the same level of integrity as reflected in the DEPs. If in doubt, the Contractor or Manufacturer/Supplier shall, without detracting from his own responsibility, consult the Principal or its technical advisor.

The right to use DEPs is granted by SIOP, SIEP or SIC, in most cases under Service Agreements primarily with companies of the Royal Dutch/Shell Group and other companies receiving technical advice and services from SIOP, SIEP or SIC. Consequently, three categories of users of DEPs can be distinguished:

1) Operating companies having a Service Agreement with SIOP, SIEP, SIC or other Service Company. The use of DEPs by these Operating companies is subject in all respects to the terms and conditions of the relevant Service Agreement.

2) Other parties who are authorized to use DEPs subject to appropriate contractual arrangements.

3) Contractors/subcontractors and Manufacturers/Suppliers under a contract with users referred to under 1) or 2) which requires that tenders for projects, materials supplied or - generally - work performed on behalf of the said users comply with the relevant standards.

All administrative queries should be directed to the DEP Administrator in SIOP.

NOTE: In addition to DEP publications there are Standard Specifications and Draft DEPs for Development (DDDs). DDDs generally introduce new procedures or techniques that will probably need updating as further experience develops during their use. The above requirements for distribution and use of DEPs are also applicable to Standard Specifications and DDDs. Standard Specifications and DDDs will gradually be replaced by DEPs.

TABLE OF CONTENTS

APPENDICES

PART I INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for the number, mass, dimensions, type, and distribution of anodes for the cathodic protection (CP) of new fixed offshore steel structures. It may also serve as a guideline if in situ replacement of a CP system is required.

This DEP is a revision of the previous publication DDD 37.19.30.30-Gen., dated September 1987.

This DEP shall only be used for seawater salinities in the range of 3.3 to 3.8%, and for temperatures in the range of 4 to 30 °C.

This DEP is based on DNV Recommended Practice RP B401, 1993 edition. Part III of this DEP gives amendments and supplements to this document.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIPM, the distribution of this DEP is confined to companies forming part of the Royal Dutch/Shell Group or managed by a Group company, and to Contractors nominated by them (i.e. the distribution code is "C" as described in DEP 00.00.05.05-Gen.).

This DEP is intended for use in offshore exploration and production facilities.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable as regards safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned with the object of obtaining agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant, authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced in this DEP are listed in (Part IV).

PART II DESIGN PHILOSOPHY

1.1 GENERAL

The CP system shall be designed to maintain the subsea metal surfaces within an electrochemical potential range which prevents subsea corrosion and material damage. This shall be achieved by supplying cathodic protection current from a distributed sacrificial anode system.

As a minimum, the CP system shall be designed for the full design life of the structure. However, the possibility of a prolonged field life requiring an extended structure life should be given due consideration.

Impressed current systems shall not be used for new installations.

An impressed current system may be considered for an offshore structure which is to serve beyond its original design life and of which the sacrificial anodes are depleted. The design of such impressed current systems is not covered in this DEP.

The CP system shall be designed to maintain the submerged steel surfaces within the electrochemical potential range of -0.800 to -1.000 volts versus Ag/AgCl/seawater.

Traditionally the Shell Group has relied solely on sacrificial anodes to prevent subsea corrosion of its offshore structures. Nevertheless, under some circumstances which result in very high current demand or anode weights, the use of sacrificial anodes alone is not considered effective or feasible; the application of a coating in conjunction with sacrificial anodes should then be adopted.

1.2 DESIGN TEMPLATE, COMPUTER SPREADSHEET

A design sheet which may be helpful to designers with the design and calculation sequence is presented in (Appendix 1). An example of its use is presented in (Appendix 2). A related computer spreadsheet is available from SIPM-EPD/63.

PART III AMENDMENTS/SUPPLEMENTS TO DNV RP B401, 1993 EDITION

This part contains "section by section" amendments/supplements to RP B401. To simplify interpretation, the section numbering herein corresponds with that in RP B401. Unamended sections in RP B401 remain valid as written.

2. SCOPE

Delete this section and refer to Section (1.1) of this DEP.

3. DEFINITIONS, SYMBOLS AND ABBREVIATIONS

3.1 PARTIES AND RESPONSIBILITIES

Replace this section with the following:

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Designer** is the Cathodic Protection Design Contractor.

The **Fabricator** is the Cathodic Protection Installation Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Operator** is the Principal.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

3.2 USE OF LANGUAGE

Replace this section with the following:

The word **may** indicates an option.

The words **shall** or **is/are to be** indicate a requirement.

The word **should** indicates a recommendation.

5. GENERAL DESIGN CONSIDERATIONS

The contents of this section are to be considered as background information only. They are technically valid but do not provide any direct guidance for designing a CP system. References to impressed current systems and pipelines are to be ignored. However, the following requirements relating to this section form part of this DEP.

5.5 DETRIMENTAL EFFECTS OF CATHODIC PROTECTION

Low-alloy steels with minimum yield stress ranging from 275 to 450 MPa are specified for substructures for fixed offshore platforms (see DEP 37.19.00.30-Gen.). As also specified in DEP 37.19.00.30-Gen., special attention should be given to the use of higher strength steels, particularly those with minimum yield stress above 400 MPa.

Quenched and tempered low-alloy steels, cold worked austenitic steels, precipitation hardened ferrous and non-ferrous alloys that are not intended for welding shall be proven compatible, by the Manufacturer/Supplier, with CP systems utilising aluminium-based sacrificial anodes.

5.7 SACRIFICIAL ANODE MATERIALS

The sacrificial anodes shall be manufactured from an indium-activated aluminium alloy. The use of other aluminium activators shall be agreed by the Principal. Tin-activated aluminium alloys shall not be used.

Mercury- or cadmium-activated aluminium alloys may only be considered under the circumstances that the indium-activated aluminium ones are proven to be ineffective in providing protection. However, statutory regulations limiting the use of these alloys may apply.

Anodes shall meet the requirements given in Section (8.) of this DEP and DEP 30.10.73.10-Gen.

The core material shall be carbon steel and comply with the specification requirements for tubular structure secondary members as specified in DEP 37.19.10.30-Gen. Core diameter and wall thickness shall be agreed with the Principal. Anode core attachment by welding shall be as specified by drawings and in conformance with the welding specification for the associated structure.

5.8 ANODE GEOMETRY

Anodes shall be of the "slender stand-off" type, with a minimum stand-off (i.e. the closest distance between the aluminium alloy and the attached steel member) of 150 mm. Anodes shall have a cylindrical or trapezoidal shape. The anode core shall exit at the anode ends.

Other anode dimensions shall be as required to meet the current density requirements of this DEP.

6. DESIGN PARAMETERS

6.1 GENERAL

Replace this section with the following:

This chapter specifies the parameters to be applied in the design of CP systems based on sacrificial anodes.

With the exception of the design life (6.2), the design parameters as defined in this DEP shall be used by the Contractor for the design of a CP system.

6.2 DESIGN LIFE

6.2.3 Replace this section with the following:

The cathodic protection shall be designed such that no planned retrofitting is required during the design life of the protected structure.

6.3 DESIGN CURRENT DENSITIES

6.3.6 Replace this section with the following:

The current density available to the structural steel surfaces shall be sufficient, at any time during the design life of the protected structure, to achieve the required potential range and maintain a calcareous deposit.

The required polarisation (initial) current density and minimum maintenance (average) current density for submerged surfaces shall be in accordance with (Figure 1) of this DEP. Locally determined maintenance current densities, if applied, shall be based upon well documented monitoring of cathode protection current densities. Locally determined values shall be provided by the Principal and documented in detail.

The maximum required polarisation current density curve as shown in (Figure 1) is considered conservative and is not expected to be exceeded.

For Zones 1 and 2 (see Section (7.2.3) in this DEP for the definition of Zones), the current densities required (a) initially, (b) averaged over the structure's lifetime, and (c) at the end of the structure's life, shall be determined in accordance with the calculations provided in (Table 1) of this DEP, taking into account the applicable coating factors. For Zone 3, i.e. buried, see Section (6.3.7).

Storm frequency (S%) shall be the percentage of the year during which the wind force exceeds 9 on the Beaufort scale. The default value shall be 25%. This figure is used in (Table 1) to determine the average (maintenance) current density requirement for Zone 1.

6.3.7 Replace this section with the following:

For bare steel surfaces buried in sediments (Zone 3), a design current density (initial/final and average) of 0.025 A/m^2 shall be used irrespective of geographical location and water depth.

6.3.8 Delete this section

6.3.9 Delete this section

6.3.10 Delete this section

6.3.11 Delete this section

6.3.12 Delete this section

6.3.13 Delete this section

6.3.14 Delete this section

6.3.15 Delete this section

6.3.17 Delete this section

6.4 COATING BREAKDOWN FACTOR AND PAINT COATINGS

6.4.4 Add to this section the following:

Where coatings are employed to reduce the wetted metal surface area, they shall meet the requirements as defined in DEP 30.48.00.31-Gen. The paint coating Category I is not applicable.

For structure nodes, the surface areas of welds and up to 0.25 m adjacent to the welds, shall be assumed to be bare and included for the calculation of current requirements.

The average and final coating coverage and breakdown factors shall be determined for the coated surface in each zone.

The constants k_1 and k_2, as defined under Category II in RP B401- Table 6.4.1, shall be used for calculating the coating break-down factors for paint coating Categories II, III and IV, i.e. k_1 = 0.05 and k_2 = 0.03 for Zone 1 and 0.02 for Zone 2.

6.4.5 Delete this section.

6.4.6 Delete this section.

6.4.10 Delete this section.

6.5 PIPELINE COATINGS

Delete this section.

6.6 SACRIFICIAL ANODE MATERIAL PERFORMANCE

6.6.1 Delete the last sentence of this section.

6.6.2 Replace this section with the following:

The sacrificial anode shall be an indium-activated aluminium alloy. Anode material shall have a capacity greater than 3.6 kg/A.yr. (efficiency = 2420 Ah/kg).

Anode material shall have a potential in the range of -1.05 to -1.15 volts versus Ag/AgCl/seawater. The number of anodes, their capacity and potential shall be sufficient to meet both the polarisation and maintenance current requirements for the steel over the design temperature range.

6.6.3 Delete this section.

6.6.4 Delete this section.

6.6.5 Replace this section with the following:

The closed circuit anode potential (E^oa) used in design calculations for determination of indium-activated aluminium anode current output (7.8.2) shall be **-**1.05 volts Ag/AgCl/seawater.

6.7 ANODE RESISTANCE FORMULAS

Replace this section with the following:

Anode resistance shall be calculated using the "Modified Dwight formula" as follows:

Anode resistance (ohm) Ra = ($\rho/2\pi L$) x (ln (4L/r) - 1)

where: ρ = seawater resistivity (ohm.cm) as per (Figure 1)
L = anode length (cm)
r = effective anode radius (cm)

For trapezoidal anode, the initial effective anode radius, r = C/2π where C (cm) = length of perimeter of cross-section.

The effective anode radius shall be calculated for the structure's final (10% anode mass remaining) anode conditions as follows:

$$r = \sqrt{(r_c{}^2 + (G / \pi L d))}$$

where: r_c = outside radius of anode core (cm)

G = remaining anode mass (kg)

d = density of anode material (kg/cm^3)

6.8 RESISTIVITY - SEAWATER

Replace this section with the following:

Seawater data used shall represent the structure's local annual average conditions versus depth. If the structure is exposed to seawater of which the temperature varies more than 5°C for a depth interval, that depth interval shall be split up into separate zones that cover no more than a 5°C interval each. The depth-averaged temperature shall be used for each zone created. Seawater resistivity (r) shall be determined from (Figure 1) or from local seawater resistivity measurements corrected to average annual seawater temperature conditions.

6.9 ANODE UTILISATION FACTOR

6.9.2 Replace this section with the following:

An anode utilisation factor of 0.90 for the long slender stand-off type shall be used.

7. DESIGN TASKS

7.1 GENERAL

Replace the first paragraph with the following:

The objective of the design calculations shall be to compute by iteration the number of anodes and anode dimensions which (1) fulfil the initial current, final current, current capacity, and current distribution requirements of the structure, and (2) provide the lowest installed cost for the CP system, including cost of anode materials, moulds, installation and coating systems (if used).

7.2 SUB-DIVISION OF OBJECT

Add new section:

7.2.3

To assure adequate and efficient use of the anode material, the submerged structure should be divided into "Zones" to be protected. Three Zones are normally classified. They are:

> Zone 1 - The zone starts from mean sea level to just above the first horizontal member below it. The depth of this zone is either the trough depth of a 100 year extreme wave or 20 m which ever is the larger. The calcareous coatings of this zone are subjected to damage by storm waves.
>
> Zone 2 - The zone below Zone 1 and above sea bottom.
>
> Zone 3 - The zone below the sea bottom mudline.

In Zone 3, instead of calculating the surface area for well casing strings extending beyond the end of the conductor, an allowance of 3 amperes per well shall be provided. This allowance shall be provided in addition to the surface area contributions from other components - e.g. conductors and piles.

The external surface area of the buried part of piles and conductors shall be included in the calculations only up to a depth of 30 m into the sea bed.

7.3 SURFACE AREA CALCULATIONS

Add new section:

7.3.7

The current drain to open skirt piles, sumps and caissons shall cover an internal surface area equivalent to 10 times π times their respective diameter.

The internal surfaces of all flooded structural members with unsealed flooding holes shall be included in the surface area calculations.

7.4 CURRENT DEMAND CALCULATIONS

7.4.2 Replace the last two lines with the following:

..... where I_c is the current demand of a specific area. i_c is to be selected from Section (6.3.6) and (Figure 1) of this DEP and f_c refers to Section (6.4.4) of this DEP.

7.4.3 Delete the last sentence.

7.5 CURRENT DRAIN CALCULATIONS

7.5.3 Replace this section with the following:

For components freely exposed to seawater, the design current density in (Figure 1) shall be applied.

7.5.4 Replace this section with the following:

For parts of steel skirts and piles to be buried in sediments, a current density (initial/final and average) of 0.025 A/m^2 shall be used. The current drain to open pipes shall cover an internal surface area equivalent to 10 times π times their respective diameter.

7.6 SELECTION OF ANODE TYPE AND DIMENSIONS

7.6.2 Delete this section.

7.7 ANODE MASS CALCULATIONS

Add to this section the following:

The following factors shall be used:

Anode Capacity	=	2420 Ah/kg or 3.6 kg/A.yr
Anode Utilisation Factor	=	0.9 (for stand-off anodes)

7.8 CALCULATION OF NUMBER OF ANODES

7.8.2 Add to this section the following:

The following factors shall be used:

Design protective potential (E^oc)	=	-0.800 Volts Ag/AgCl/seawater
Design closed circuit potential (E^oa)	=	-1.050 Volts Ag/AgCl/seawater

7.8.3 Replace this section with the following:

The anode current output shall be calculated for the initial and final life of the CP system.

In the latter case anodes of 10**%** remaining mass shall be used. Calculations of initial and final anode resistance shall be in accordance with Section (6.7) of this DEP.

7.8.5 Delete this section.

7.8.7 Add to this section the following:

The number of anodes shall be computed for the structure's initial and final currents, and the structure's current capacity, by zone, as follows:

Anodes for initial current needs (n)	=	I_c (initial) / I_a (initial)
Anodes for final current needs (n)	=	I_c (final) / I_a (final)
Anodes for current capacity (n)	=	M / m [m = Mass of Anode Material per Anode]

The number of anodes provided within each zone shall be greater than the required numbers as calculated, by zone, and also greater than the minimum number of anodes required to assure adequate current capacity and proper current distribution.

The total number of anodes required shall be the sum of those needed for the three zones.

7.9 DETAILED ANODE DESIGN

7.9.3 Delete this section.

7.9.5 Delete this section.

7.9.7 Delete the second sentence of this section.

7.10 DISTRIBUTION OF ANODES

7.10.1 Add to this section the following:

Anode placement shall be marked on the relevant drawings. Where anodes of a different type or weight are present, the drawings shall distinctly mark their placement.

Sequential priority for anode placement should be based upon the following:

1) Anode distribution should normally begin with placement upon larger members (e.g. legs) near nodes and continue to minor members.
2) Placement shall consider future added components (e.g. new conductors and risers).
3) Locations where attenuation effects will reduce good current distribution - (e.g. conductor clusters, complex pile guides) shall require a higher anode concentration.

7.10.4 Add to this section the following:

Anode distribution shall comply with the following requirements:

1) Anodes shall be placed within 15 m of adjacent anodes.
2) Anodes shall be placed within 10 m of surfaces to be protected.

Proper anode placement should be performed as an iterative process, in which initial design drafts are adjusted to an optimum configuration, using the above guidelines. The placement process may result in conservative adjustments to anode dimensions and addition to the calculated total number to assure adequate current distribution.

Anodes designed to protect the buried surface area shall all be installed on the bottom elevation of the structure.

7.10.5 Delete this section.

7.11 ANODE MOUNTING AND PROVISIONS FOR ELECTRICAL CONTINUITY

7.11.1 Add to this section the following:

The design of anode mounting shall take the following into consideration:

1) Hydrodynamic forces on the anodes, strength of the structural member and the long term fatigue effect from the environmental loading.
2) Effect from the launching process of a launch-installed jacket (clear launch path, hydrodynamic forces on the anodes during launching).
3) Effect of pile and conductor driving forces on the welded anode connections (punch - through).
4) Possible interference with the installation of risers and riser clamps.

7.11.3 Replace this section with the following:

With items subject to high external loads, the need for any doubler plates for welded anode supports shall be considered.

7.11.4 Delete this section.

7.11.5 Delete this section.

7.11.6 Delete this section.

7.11.7 Replace this section with the following:

Metallic contact or electrical continuity between the conductor pipes and other objects cathodically protected by anodes shall be provided by welding lugs and a connecting cable between them. The voltage drop of each connection shall not exceed 10% of the design driving voltage, i.e. 0.025 V. Proper welding procedures shall be applied which are in compliance with the structural material concerned.

Piles shall be assumed to be in metallic contact with their guide sleeves, unless insulated by centralised, non-conductive materials.

7.11.8 Delete this section.

7.11.9 Delete this section.

Add new section:

7.11.10

Anode material shall not be painted.

All anode locations shall be shown only once in the drawings, in the plan or elevation where they shall be mounted.

Anodes shall be mounted as follows:

a) Anodes upon horizontal members should be preferably mounted on the bottom side, except anodes on the bottom horizontal member which shall be top-mounted.
b) Anodes for legs shall be rotated inboard 45 to 90 degrees.
c) Other anodes within elevations shall be planar oriented and preferably bottom-mounted.
d) Anodes shall be re-oriented or locally relocated as needed to avoid obstructing launch way, conductor, pile, or riser guide paths.
e) Anode material shall clear all member surfaces by a minimum of 150 mm.
f) Anode stand-off welds shall clear any other weld by a minimum of 150 mm.
g) Anodes shall clear nodes by a minimum of 1.5 m.
h) Anodes shall be mounted at least 1 m below the lowest astronomical tide (LAT) level.

Welding procedures for stand-off attachment shall be qualified for the welds to be made.

7.12 ENGINEERING DOCUMENTATION

Add to this section the following:

The design data shown in (Appendix 1) of this DEP shall be documented by the Contractor and submitted to the Principal for approval.

Anode design data such as shown in (Appendix 2) of this DEP as a worked example, shall be documented by the Contractor and submitted to the Principal for approval.

8. MANUFACTURING OF SACRIFICIAL ANODES

8.2 QUALIFICATION OF ANODE MANUFACTURING

Replace this section with the following:

Anode manufacturing shall be carried out according to a qualified procedure. Anodes shall be pre-qualified by the Manufacturer in accordance with (Appendix 3) of this DEP before they can be approved for the application.

As part of the pre-qualification requirements, anode manufacturers shall submit the following data to the Principal and seek for their approval: - anode/core preparations, casting precaution measures, chemical composition ranges, potential and capacity limits, surface defects (visual inspection), anode to core bonding (destructive test), weight and dimensional tolerances and certification/documentation format.

8.3 STANDARDS

Replace this section with the following:

Requirements for manufacturing of anodes are given in NACE RP0387-87 for offshore anodes.

9. INSTALLATION OF SACRIFICIAL ANODES

9.2 PIPELINE ANODES

Delete this section.

10. IMPRESSED CURRENT CATHODIC PROTECTION SYSTEMS

Delete this Chapter.

11. INSPECTION AND MONITORING OF CATHODIC PROTECTION

11.5.3 Delete this section.

Add new section:

11.9 SURVEY AND SURVEY LEVELS

Survey inspections shall be conducted in accordance with DEP 37.19.00.30-Gen.

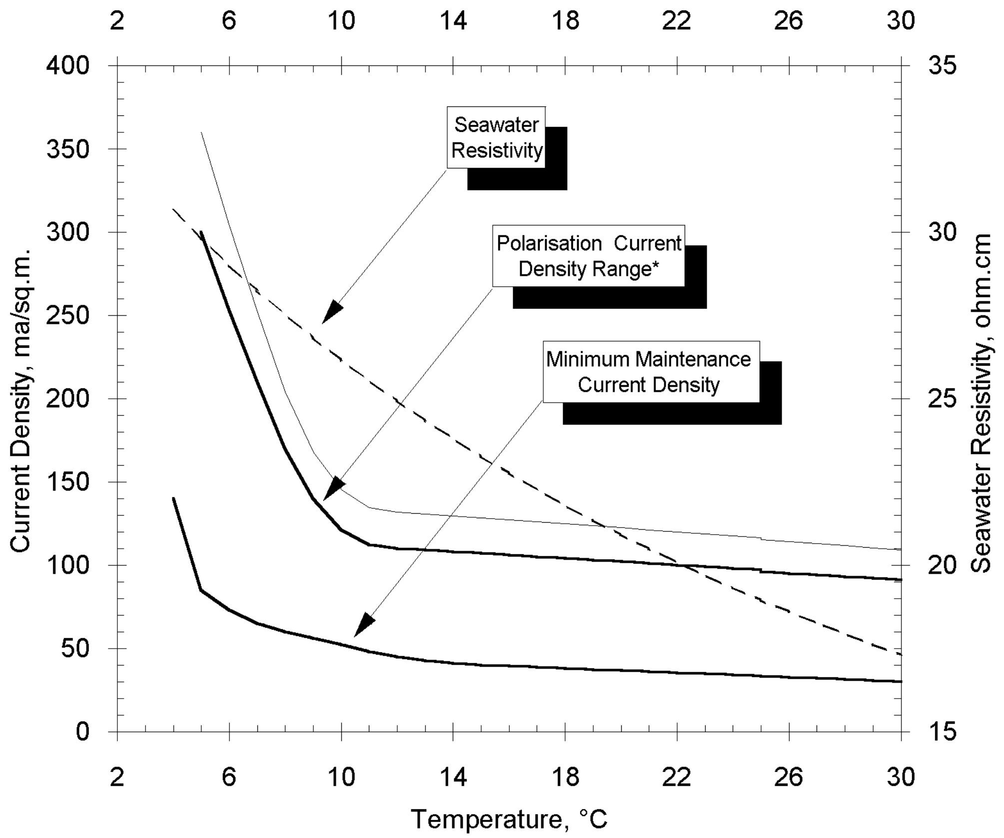
TABLE 1 REQUIRED CURRENT DENSITY IN ZONES*

Phase	Current Density Requirements*		
	Zone 1	Zone 2	Zone 3
Initial:	i_c (initial) x f_c	i_c (initial) x f_c	
Average lifetime (maintenance):	((1-S%/100) i_c (average) + (S%/100) i_c (initial)) f_c	i_c (average) x f_c	25 mA/m^2
Final:	i_c (initial) x f_c	i_c (average) x f_c	

* Current densities i_c(initial) and i_c(average) vary with temperature (see Figure 1), f_c varies with respective zones and design life (see RP B401 Figure 6.4.2), and S is the storm frequency with a default value of 25% (see Section (6.3.6) of this DEP).

FIGURE 1 DESIGN PARAMETERS AS A FUNCTION OF SEAWATER TEMPERATURES

Polarisation (Initial) and Maintenance (Average) Current Density and Seawater Resistivity



* NOTE: The lower Polarisation Current Density curve is the minimum requirement. The upper curve is meant for sensitivity analysis. For Driving Voltages other than 0.25 Volts, multiply the polarisation current density values by 0.25/Driving Volts, where Driving Volts = -0.80 - (Anode Operating Potential)

PART IV REFERENCES

In this DEP reference is made to the following publications:

NOTE: Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments/supplements/revisions thereto.

SHELL STANDARDS

Index to DEP publications and standard specifications	DEP 00.00.05.05-Gen.
Cathodic protection	DEP 30.10.73.10-Gen.
Painting and coating of new equipment	DEP 30.48.00.31-Gen.
Design of steel substructures for fixed offshore platforms	DEP 37.19.00.30-Gen.
Weldable structural steels for fixed offshore structures	DEP 37.19.10.30-Gen.

AMERICAN STANDARDS

Substitute Ocean Water	ASTM D 1141

Issued by:
American Society for Testing and Materials
1916 Race Street
Philadelphia 19103
USA.

NORWEGIAN STANDARDS

Recommended Practice - Cathodic Protection Design	DNV RP B401 (1993)

Issued by:
Det Norske Veritas Industri Norge AS
PO Box 300
N-1322 Høvik
Norway.

BIBLIOGRAPHY

NOTE: The following documents are for information only and do not form an integral part of this DEP.

Planning, Designing and Constructing Fixed Offshore Platforms - Load and Resistance Factor Design	API RP2A-LRFD
Recommended Practice for Planning, Design and Constructing Fixed Offshore Platforms - Working Stress Design	API RP2A-WSD

Issued by:
American Petroleum Institute
1220 L Street Northwest
Washington, DC 20005
USA.

APPENDIX 1 DESIGN SHEET - CATHODIC PROTECTION OF OFFSHORE STRUCTURES

DATA SHEET - ____

Structure Data						
Structure identification:						
Structure location:						
Reference drawing and date:						
Maximum estimated structure life, yr:					Storm frequency, %:	*25
Average bottom water depth, m:					Storm wave, m:	*20
Seawater Data for Location	**Zone 1**		**Zone 2**			**Zone 3**
Depth interval to plan break:						Bottom
Temperature, °C:						
Salinity, %:						N.A.
Average resistivity, ohm.cm:						
Cathode Design						
Cathode Potential Range						
Maximum, volts re Ag/AgCl in SW:	-0.800	Minimum, Volts re Ag/AgCl in SW:				-1.000
Subsea Surface Area						
Surface area, no coating, m^2:						
Surface area, coated surfaces, m^2:						N.A.
Number of wells:			N.A.			
Coating Breakdown Factor, Coated Surfaces						
Initial:						
Average lifetime:						N.A.
Final:						
Current Densities at Temperature						
Minimum for polarisation, mA/m^2:						
Maximum for polarisation, mA/m^2:						25
Minimum for maintenance, mA/m^2:						
Current Density, No Coating						
Initial minimum, mA/m^2:						
Initial maximum, mA/m^2:						
Average lifetime, mA/m^2:						25
Final minimum, mA/m^2:						
Final maximum, mA/m^2:			N. A.			
Current Density, Coated Surfaces						
Initial minimum, mA/m^2:						
Initial maximum, mA/m^2:						
Average lifetime, mA/m^2:						N.A.
Final minimum, mA/m^2:						
Final maximum, mA/m^2:			N. A.			
Galvanic Anode Design						
Manufacturer:		Material trade name:				
Alloy components:					Utilisation factor:	*0.9
Anode Dimension, Weight, and Core Data						
Average dimensions, L x W x H or L x OD cm:						
Dry mass of anode material, kg each:		Anode density, kg/cm^3:				
Anode total dry mass, kg each:		Anode total wet mass, kg each:				
Core, outer radius x wall, cm:		Material:				
Anode Material Performance Data -						
Polarisation operating potential, volts re Ag/AgCl in SW:	-1.05*					
Maintenance operating potential, volts re Ag/AgCl in SW:	-1.05*					
Maintenance operating capacity, Ah/kg:	3.6*					

* Default values, which may be changed on the basis of detailed review of the specific case.

APPENDIX 1 (cont.) DESIGN SHEET - CATHODIC PROTECTION OF OFFSHORE STRUCTURES

DATA SHEET - ____

Design Calculations						
Total Anode Current Demand	**Zone 1**	**Zone 2**				**Zone 3**
Initial minimum, amp.:						
Initial maximum, amp.:						
Average lifetime, amp.:						
Final minimum, amp.:						
Final maximum, amp.:		N. A.				
Total Current Capacity						
Mass anode material required, kg:						
Structure Anode Design Calculations						
Anode Resistance						
Initial effective radius, cm:		Final effective radius, cm:				
Initial anode resistance, ohm:						N.A.
Final anode resistance, ohm:						
Anode Output						
Initial anode output, amp.:						N.A.
Final anode output, amp.:						
Number Anodes Required	**Zone 1**	**Zone 2**				**Zone 3**
For initial minimum current needs:						
For initial maximum current needs:						
For final minimum current needs:						
For final maximum current needs:		N. A.				
For maintenance capacity needs:						
Anodes Design Requirement						
Total anodes required for zones:						
		Total anodes required =				
Anode placement drawing and date:						

APPENDIX 2 DESIGN EXAMPLE

The following example employs the template in Appendix 1 as a method of demonstrating the design and calculation sequence. Data added to the form are shown in *italics*.

DATA SHEET - *Structure "CP-1"*

Record structure and local seawater data as needed (e.g. Note that only two columns of Zone 2 data are completed.). Consult Section (6.) for detailed data requirements.

Structure Data						
Structure identification:	*SIPM CP1*					
Structure location:	*52°N, 4°E*					
Reference drawing and date:	*ABC - 1 through 20, 3 Jan. 93*					
Maximum estimated structure life, yr:	*30*				Storm frequency, %:	*20*
Average bottom water depth, m:	*150*				Storm wave, m:	*20
Seawater Data for Location	**Zone 1**	**Zone 2**				**Zone 3**
Depth interval to plan break:	*25*	*75*	*Bottom*			Bottom
Temperature, °C:	*17°*	*12°*	*7°*			
Salinity, %:	*3.5%*	*3.5%*	*3.5%*			N.A.

Determine seawater resistivity corresponding to temperature using (Figure 1) or computer spreadsheet.

Average resistivity, ohm.cm:	*22.3*	*24.9*	*28.2*			N.A.

Record structure cathode design data. Consult Section (6.) for detailed data requirements.

Cathode Design			
Cathode Potential Range			
Maximum, volts re Ag/AgCl in SW:	-0.800	Minimum, volts re Ag/AgCl in SW:	-1.000

For surface area calculations, plan breaks at suitable depth are often used to separate Zones. Within a zone, there is a split between coated and uncoated surfaces. Structure "CP-1" is assumed to be exposed to cold water with the majority of member surfaces coated, but coating is not applied for nodes, mud mats, nor coating-damage prone conductors and conductor guides. Number of wells only applies to Zone 3.

Subsea Surface Area						
Surface area, no coating, m^2:	*1011*	*2322*	*1103*			*1521*
Surface area, coated surfaces, m^2:	*0*	*0*	*2830*			N.A.
Number of wells:	N.A.					*8*

The coating breakdown factors are calculated as needed, using the formulas in RP B401 Table 6.4.1.

e.g. in Zone 2 the Average Lifetime Coating Factor = 0.05+(0.02x30/2) = 0.35 .

Coating Breakdown Factor, Coated Surfaces						
Initial:			*0.05*			N.A.
Average lifetime:			*0.35*			
Final:			*0.65*			

The current densities are identified using (Figure 1) or the computer spreadsheet, for each temperature interval.

Current Densities at Temperature						
Minimum for polarisation, mA/m^2:	*105*	*110*	*210*			25
Maximum for polarisation, mA/m^2:	*126*	*132*	*252*			
Minimum for maintenance, mA/m^2:	*38.7*	*45.0*	*65.0*			

APPENDIX 2 (cont.) DESIGN EXAMPLE

The current densities for bare surfaces are calculated using the formulas in (Table 1) and the previously determined values, with Coating Factor = 1.0.

e.g. in Zone 1 the Initial Minimum = i_c(initial) x 1.0 = 105.

Current Density, No Coating						
Initial minimum, mA/m²:	*105*	*110*	*210*			25
Initial maximum, mA/m²:	*126*	*132*	*252*			
Average lifetime, mA/m²:	*51.9*	*45*	*65*			
Final minimum, mA/m²:	*105*	*45*	*65*			
Final maximum, mA/m²:	*126*	N. A.				

The current densities for coated surfaces are calculated, as needed, using the formulas in (Table 1) and the previously determined values.

e.g. the Initial Minimum = i_c(initial) x f_c = 210 x 0.05 = 10.5.

Current Density, Coated Surfaces						
Initial minimum, mA/m²:			*10.5*			N.A.
Initial maximum, mA/m²:			*12.6*			
Average lifetime, mA/m²:			*22.8*			
Final minimum, mA/m²:			*42.3*			
Final maximum, mA/m²:		N. A.				

Record galvanic anode data. Consult Section (6.) for detailed data requirements.

Galvanic Anode Design			
Manufacturer:	*OKed Co.*	Material trade name:	*OK-Al-1*
Alloy components:	*Bal.Al; .0#%In; #%Zn; .#%Si; .#%Fe*	Utilisation factor:	*0.9

The anode dimensions given below are the result of an iterative procedure. In this procedure, after defining the maximum anode mass (e.g. typically 400 kg) and maximum anode length (e.g. typically 250 cm), different combinations of anode mass and length were tested, resulting in selection of optimum anode dimensions. Factors assessed also included anode distribution requirements, anode material cost per kg, and total installed cost per anode. In rare cases, typically on structures taller than 250 m, more than one anode size may be needed.

Anode Dimension, Weight, and Core Data			
Average dimensions, L x W x H or L x OD cm:	*250 x 15.8*		
Dry mass of anode material, kg each:	*245*	Anode density, kg/cm³:	*0.00275*
Anode total dry mass, kg each:	*250*	Anode total wet mass, kg each:	*110*
Core, outer radius x wall, cm:	*11.5 x 0.9*	Material:	*ASTM A-106Gr.B*

The default values are used for anode performance, per Section (7.7) and (7.8.2).

Anode Material Performance Data	
Polarisation operating potential, volts re Ag/AgCl in SW:	-1.05*
Maintenance operating potential, volts re Ag/AgCl in SW:	-1.05*
Maintenance operating capacity, Ah/kg:	3.6*

* Default values, which may be changed on the basis of detailed review of the specific case.

APPENDIX 2 (cont.) DESIGN EXAMPLE

DATA SHEET - ***Structure "CP-1"***

Design Calculations

The total structure current is then calculated, by zone and temperature interval according to Section (7.4).

e.g. the Zone 1 initial minimum =

$(\{[i \times A]_{\text{Bare Surfaces}} + [i \times A]_{\text{Coated Surfaces}}\}_{\text{Initial}} / 1000)$ + Well Allowance = (105 x 1011)/1000 + 0 = 106

Total Anode Current Demand	**Zone 1**	**Zone 2**				**Zone 3**
I_c(initial) minimum, amp.:	*106*	*255*	*261*			
I_c(initial) maximum, amp.:	*127*	*307*	*314*			
I_c(average) lifetime, amp.:	*52.5*	*104.5*	*136.1*			*62.0*
I_c(final) minimum, amp.:	*106*	*104*	*191*			
I_c(final) maximum, amp.:	*127*	N. A.				

The total anode current capacity is then calculated, by zone and temperature interval according to Section (7.7) where anode capacity/efficiency is 3.6 kg/A.yr. (instead of the equivalent 2420 Ah/kg).

e.g. the Zone 1 mass anode material =

I_c (average) x Life (yr.) x Anode Capacity / Anode Utilisation Factor = 52.5 x 30 x 3.6 / 0.9 = 6300

Total Current Capacity						
Mass anode material required, kg:	*6,300*	*12,539*	*16,329*			*7,443*

Anode design calculations are performed in accordance with Section (6.7). The initial and final anode radius are calculated using the equations in Section (6.7).

e.g. Final Effective Radius = $\sqrt{(r_c^2 + (G/\pi Ld)}$ = $\sqrt{(11.5^2 + ((0.1 \times 245)/(\pi \times 250 \times .00275))}$ = 11.98

Structure Anode Design Calculations			
Anode Resistance			
Initial effective radius, cm:	*15.68*	Final effective radius, cm:	*11.98*

The initial and final anode resistance are also defined by the equations in Section (6.7), and by the seawater resistance in each temperature interval.

e.g. Zone 1 Initial Anode Resistance = $(\rho / 2\pi L) \times (\ln (4L/r) - 1)$ =

$[22.3 / (2 \times \pi \times 250)] \times [\ln (4 \times 250 / 15.68) - 1] = 0.0447$

Initial anode resistance, ohm:	*0.0447*	*0.0501*	*0.0567*			N.A.
Final anode resistance, ohm:	*0.0485*	*0.0543*	*0.0616*			

The initial and final anode output are defined by the equations in Section 7.8.2 of RP B401.

e.g. Zone 1 Initial Anode Output = (-0.800 - (-1.050)) / 0.0447 = 5.59

Anode Output						
Initial anode output, amp.:	*5.59*	*4.99*	*4.41*			N.A.
Final anode output, amp.:	*5.15*	*4.60*	*4.06*			

APPENDIX 2 (cont.) DESIGN EXAMPLE

The number of anodes required by the structure's total current demand is defined in Section 7.8.4 of RP B401.

e.g. in Zone 1 to satisfy the initial minimum current, the number of anodes = 106 / 5.59 = 19.0

Number Anodes Required	**Zone 1**	**Zone 2**				**Zone 3**
For initial minimum current needs:	*19.0*	*51.2*	*59.3*			
For initial maximum current needs:	*22.8*	*61.4*	*71.2*			
For final minimum current needs:	*20.6*	*22.7*	*47.1*			*30.4*
For final maximum current needs:	*25.7*	N. A.				

e.g. in Zone 1 to satisfy the maintenance capacity, the number of anodes = 6301 / 245 = 25.8

For maintenance capacity needs:	*25.8*	*51.2*	*66.6*			

The numbers of anodes required to meet all the initial minimum requirements are then summarised.

Anodes Design Requirement						
Total anodes required for zones:	*26*	*52*	*67*			*31*
					Total anodes required =	***176***

Upon completion of the anode calculation process, anodes are distributed about the structure in accordance with Section (7.10) in this DEP. If during the distribution process it is found that far too few anodes are available, it will be necessary to repeat the calculations using smaller anode weights.

Anode placement drawing and date:	*ABC - 21, 4 Jan. 1993*

APPENDIX 3 ELECTROCHEMICAL TEST PROCEDURES FOR SACRIFICIAL ANODES

1. INTRODUCTION

Appendix 3 of this DEP addresses the requirements for prequalification testing of anodes before they can be approved for the application. Appendix A of the DNV RP B401 is applicable for quality control during production of sacrificial anodes.

The objective of the tests is to assess the compliance of the anode material's passivation and current capacity properties with the design data submitted by the Manufacturer. The suitability of the anode material for a particular design shall be judged from case to case using the above information.

Potentiostatic tests are to be carried out to measure the anode material's tendency to passivation.

Galvanostatic tests are to be carried out to determine the anode material's current capacity and its tendency for intergranular corrosion.

When both tests have been passed, the anode material has been qualified.

This document describes the test procedures of these tests, to be carried out by a nominated test laboratory.

Each test shall be carried out in duplicate. Both results shall be acceptable for the material to pass the test.

The tests shall be carried out on test samples, fully representative for the proposed type of anode material.

2. ANODE DESIGN DATA

The following design data shall be submitted by the Supplier of the anode:

- the Manufacturer's name, the type and/or trade name of the anode material;
- the anode material specification;
- the nominal chemical composition ranges of the anode material;
- the date of manufacture and heat number of the test samples;
- a full chemical analysis of the anode sample materials;
- the nominal free corroding potential of the anode material in mV versus.SCE or Ag/AgCl;
- the maximum and minimum design current density of the anode material in mA/cm^2;
- the nominal design current capacity of the anode material in Ah/kg.

3. TEST ENVIRONMENT

The test environment shall be artificial seawater.

The seawater shall be prepared in accordance with ASTM D 1141 with the exception of the addition of Magnesium salts. The indicated quantity of MgCl shall be replaced by the stoichiometric equivalent in NaCl (viz. 3889 g MgCl in stock solution 1 shall be replaced by 3803 g NaCl).

The volume of seawater shall be sufficient to avoid contamination of the seawater with corrosion products from the samples, produced during the test and to avoid changes in concentration due to normal evaporation losses. Minimum volumes are given in the test procedures below.

4. TEST TEMPERATURE

The test temperature shall be determined to simulate the actual operating temperature of the anode to be encountered in the field and shall be agreed with the Principal before the tests are carried out.

Test temperatures shall be defined by the Principal. As a guide, for North sea applications a temperature of 5 °C should be used, for other seawater applications a test temperature of 20 °C should be used.

The temperature of the test solution shall be thermostatically controlled.

Tests at 20 °C may be carried out without thermostatic control at room temperature provided that this temperature is between 18 and 22 degrees and the minimum and maximum temperature are measured during the tests.

5. SAMPLE IDENTIFICATION

The anode samples shall be cut or machined from two different blocks of anode material from the same melt or from different melts.

Each sample shall be provided with a unique identification code e.g. by engraving in the embedding material.

6. ANODE PASSIVITY TEST PROCEDURE

6.1 PROCEDURE

A sample of anode material is provided with an electrical test lead and embedded in a suitable resin. The exposed test surface shall be in one plane. The exposed surface area shall be between 150 and 400 mm^2 and shall be accurately measured and reported.

NOTE: Sample size of dia = 16 mm, L = 20 mm is recommended, surface area of circular section = 201 mm^2.

Prior to the test, the test surface is ground using 180 grit abrasive paper.

For each test sample a minimum of 1 litre of test solution is prepared.

The sample is immersed in the test environment and the free corroding potential is determined with respect to a Saturated Calomel Electrode (SCE) or a Silver/Silverchloride (Ag/AgCl) reference electrode.

The reference electrode system is to be provided with a Haber Luggin capillary, which is positioned about 1 mm from the sample's surface. An auxiliary (counter) electrode shall be a bright platinum mesh or another inert material of about 10 cm^2 placed opposite the test surface.

When stabilised, the free corroding potential Eo is recorded.

Using a potentiostat, the potential of each of the samples is now controlled at various potentials more positive than the free corrosion potential (Eo) in the following sequence:

Period 1: Eo+50 mV

Period 2: Eo+100 mV

Period 3: Eo+200 mV

Period 4: Eo+100 mV

The duration of each period shall be between 66 and 72 hours.

During the test the position of the tip of the Haber Luggin capillary may have to be adjusted if high corrosion rates would be encountered.

The current, required to maintain the test potential, shall be recorded continuously during the test.

The minimum current and the average current over the last 24 hours of each period shall be determined from these measurements. The average current is determined by calculating the arithmetic mean of the current values at the time 24, 18, 12, 6 and 1 hour before the end of each test period.

The applied current densities are determined by dividing the measured currents by the sample surface area.

The current densities for each of the test potentials are plotted against time.

The minimum and average current densities are plotted against the applied potential.

6.2 PASS/FAIL CRITERIA

The sample passes the anode passivity test:

- if the average current density during three or four of the test periods is not less than the minimum design current density;
- if the average current density during test period 4 is not less than 50% of the average current density during test period 2;
- if the minimum current density is not less than 50% of the average current density during the last 24 hours of any of the test periods.

In all other cases the samples have failed the tests.

7. ANODE CURRENT CAPACITY TEST PROCEDURE

7.1 PROCEDURE

A cylindrical sample of anode material is provided with an electric lead. The lead contact shall be sealed using a suitable epoxy resin.

The total mass of the sample shall be sufficient to last for at least three times the test duration of the test based on the actual current capacity.

The shape of the sample shall be such as to maintain the same exposed surface area (within 10%) throughout the test.

The exposed surface area should be accurately known (approximately 10 cm^2).

NOTE: Typical test sample sizes are dia = 5 mm, L = 62.5 mm or dia = 10 mm, L = 30 mm).

The anode surface shall be prepared before the test as follows:

Aluminium anodes are etched in a 10% aqueous Sodium hydroxide (NaOH) solution for one minute, rinsed in tap water, cleaned for five seconds in a 10% solution of Nitric Acid (HNO_3), rinsed in tap water, rinsed with acetone and dried in air.

The samples are to be weighed before exposure.

The samples are placed in a cylindrical steel container, diameter 15 cm, height 25 cm which functions as an auxiliary electrode. The container is filled with the test environment (seawater) and a SCE or Ag/AgCl reference electrode is installed with the tip of the Haber Luggin capillary at 1 mm from the sample surface.

A constant direct current is passed between the container and the sample such that the sample is subjected to an anodic current. The current is adjusted to obtain a current density on the exposed surface of the sample of 0.2 mA/cm^2 (current approximately 2 mA) for exposure in seawater.

The minimum test duration shall be 30 days.

During the tests the potential of the samples shall be measured at least two times per day or by continuous registration.

At the end of the test the samples are cleaned by hosing off with tap water, etched as before the test, rinsed with tap water, rinsed with acetone and dried in air.

The samples are weighed and the weight loss is determined. The total charge passed through the sample is determined in ampere-hours (Ah) and the current capacity is calculated, expressed in Ah/kg.

The sample shall be investigated metallographically for the presence of intercrystalline corrosion. For this investigation the cylindrical sample shall be cut in an axial direction, ground using fine (720 grit) abrasive paper and etched in an appropriate etchant.

Photographic evidence of the surface shall be produced (enlargement 10x).

7.2 PASS/FAIL CRITERIA

The sample passes the anode capacity test:

- if the measured current capacity of the anode material is not less than the design capacity specified by the supplier;
- if the measured potential shows no excursions of more than 50 mV more positive than the average potential during the test and more than 100 mV more positive than the free corroding potential, Eo, as determined in the Passivity test.

  When there is an indication of intergranular corrosion of the sample, the test shall be repeated for a duration of 90 days, the results of which shall satisfy the above requirements.

In all other cases the samples have failed the tests.

8. TEST REPORT

A test report shall be produced in duplicate and shall contain at least the following information:

- all design data as required in Section (2.) of this Appendix;
- reference to or a copy of these procedures;
- the date and place of manufacturing and a description of the sample preparation;
- the name and place of the test facilities and the name of the person responsible for the testing;
- the name of the Principal's representative who witnessed the test;
- a description of the test apparatus and (if applicable) brand names and types of the equipment used;
- a list of all measured and calculated current density, potential and weight values and/or copies of relevant recorder charts or graphs;
- the current density/potential graphs the current density/time graphs and the potential/time graphs as described in the test procedures;
- micrographs of the sections of the samples made during the metallographic examination;
- any other observations made during the tests which are regarded of importance to support the conclusions;
- conclusion drawn from the test results with the pass/fail result as described above.

The final report shall be signed by the responsible person of the test laboratory and, if applicable, by the Principal's representative(s), witnessing the tests.