HSE
Health & Safety
Executive

Corrosion protection

OFFSHORE TECHNOLOGY REPORT
2001/011

Corrosion protection

Edited under the HSE Technical Support Agreement by BOMEL Ltd
Ledger House
Forest Green Road
Fifield
Maidenhead
Berkshire
SL6 2NR

HSE BOOKS

First published 2002

ISBN 0 7176 2383 1

CONTENTS

FOREWORD

This document provides technical information previously contained in the Fourth Edition of the Health and Safety Executive's *'Offshore Installations: Guidance on Design, Construction and Certification'* (1990 edition plus amendments)[(1)]. The 'Guidance' was originally published in support of the certification regime under SI289, the Offshore Installations (Construction and Survey) Regulations 1974[(2)]. However, SI289 was revoked by the Offshore Installations (Design and Construction, etc) Regulations, 1996, which also introduced the verification provisions into the Offshore Installations (Safety Case) Regulations, 1992. The 'Guidance' was formally withdrawn in its entirety on 30 June 1998 (see HSE OSD Operations Notice 27[(3)]).

The withdrawal of the 'Guidance' was not a reflection of the soundness (or otherwise) of the technical information it contained; some sections (or part of sections) of the 'Guidance' are currently referred to by the offshore industry. For this reason, after consultation with industry, relevant sections are now published as separate documents in the HSE Offshore Technology (OT) Report series.

It should be noted that the technical content of the 'Guidance' has not been updated as part of the re-formatting for OTO publication, although prescriptive requirements and reference to the former regulatory regime have been removed. **The user of this document must therefore assess the appropriateness and currency of the technical information for any specific application. Additionally, the user should be aware that published sections may cease to be applicable in time and should check with Operations Notice 27, which can be viewed at http://www.hse.gov.uk/hid/osd/notices/on_index.htm, for their current status.**

1. INTRODUCTION AND SCOPE

1.1 SOURCE OF INFORMATION

This Offshore Technology (OT) Report provides technical information on the protection of Offshore Installations against corrosion. It is based on guidance previously contained in Section 12 of the Fourth Edition of the Health and Safety Executive's 'Offshore Installations : Guidance on Design, Construction and Certification'[1] which was withdrawn in 1998. As discussed in the Foreword, whilst the text has been re-formatted for Offshore Technology publication, the technical content has not been updated. The appropriateness and currency of the information contained in this document must therefore be assessed by the user for any specific application.

1.2 REFERENCE DOCUMENTS ON CATHODIC PROTECTION

Practical guidance on the design and operation of effective cathodic protection systems offshore is given in MTD Publication 90/102 (1990)[4].

A number of standards and codes of practice (NACE 1976[5], BS CP 1021:1973[6], FIP/6/1[7], DnV TNA 703[8]) give general guidance on cathodic protection. None of them, however, can be regarded as definitive for North Sea application.

2. CORROSION ZONES

When considering the degree of surface protection necessary for an Offshore Installation, the structure should be divided into zones or areas as defined below and corrosion protection afforded accordingly.

2.1 STEEL STRUCTURES

For steel structures the degree of exposure of an Offshore Installation for corrosion protection should be considered in three external zones and two internal zones as follows:

- External Zones
  - i) submerged zone: that part of the structure below the splash zone;
  - ii) splash zone: that part of the structure between the crest level of the 50-year (average) wave superimposed on the highest astronomical tide, and 3 metres below the lowest astronomical tide;
  - iii) atmospheric zone: that part of the structure above the splash zone.

  Note: Structures continuously exposed to salt-laden air are often as vulnerable to attack as those in the splash zone.

- Internal Zones
  - i) submerged zone: that part of the structure in contact with oil, sea water or other liquids;
  - ii) atmospheric zone: that part of the structure above the submerged zone.

2.2 CONCRETE STRUCTURES

For concrete structures, the internal exposure zones are identical to those for steel structures given in Section 2.1. The external exposure zones are also identical, except that the splash zone extends down to the lowest astronomical tide (in accordance with FIP recommendations(7)).

3. PROTECTION AGAINST CORROSION

3.1 PROTECTION OF STEEL

Steel structures should be treated according to zone as follows:

- The splash zone should be protected by one or more of the following methods:
  - i) extra steel in excess of that needed for strength;
  - ii) suitable claddings or wraps;
  - iii) suitable coatings.

- The atmospheric zone should be protected by suitable coatings of selected materials. The surface preparation and application procedures should follow the manufacturer's recommendations and must be rigorously controlled.

- The external submerged zone should be protected by cathodic protection and/or other suitable means.

- Any internal free flooding submerged zone should be protected by one or more of the following methods:
  - i) extra steel in excess of that needed for strength;
  - ii) suitable coatings;
  - iii) cathodic protection.

- For closed flooding compartments the following methods are also available:
  - i) the use of corrosion inhibitors;
  - ii) the exclusion of oxygen and the use of a suitable biocide.

In all cases the chosen method should be well documented to demonstrate its suitability and effectiveness.

3.2 CATHODIC PROTECTION (STEEL STRUCTURES)

Cathodic protection is required for all external submerged steelwork in order to prevent excessive general metal loss, to prevent localised corrosion and to minimise corrosion fatigue.

Cathodic protection may be applied either independently of, or in conjunction with, a coating or wrap system to reduce current requirements and improve uniformity of current distribution. Where coatings are used consideration should be given to the rate and extent of deterioration of the coating and the provision of increased cathodic protection as a result of this deterioration. Excessive levels of cathodic protection should be avoided to minimise the possibility of disbondment of coatings and the possibility of hydrogen absorption, leading to hydrogen assisted cracking of sensitive steels or weld heat-affected zone.

For internal flooded steelwork cathodic protection may be employed either with or without coatings, cladding, or corrosion inhibitors. In closed vessels in the absence of oxygen the possibility of anaerobic microbial corrosion should be considered. Free flooding systems require particular care to ensure that corrosion protection is available in all operational states. Particular attention should be paid to current distribution in heavily stiffened areas.

All parts of the protected structure should be electrically continuous unless, for particular operational reasons, the system is subdivided in which case the continuity of each individual portion should be assured. Where independent systems are necessary, adequate electrical insulation between the separate cathodic protection systems is required.

Where a system is sub-divided, or where there are adjacent Installations, there is a possibility of accelerated corrosion from interaction effects. These effects must be taken into account in the design and investigated as early as possible in the life of the structure so that any appropriate remedial measures can be implemented before significant corrosion has taken place.

The following items should be noted and consideration given to their implications for the system design:

i) The current distributed to all parts of the structure should be adequate for protection for the duration of the design life.

ii) The distribution of current should avoid excessive levels of cathodic protection to minimise damage due to hydrogen absorption and consequent hydrogen assisted cracking.

iii) Where impressed current systems are utilised, alternative cathodic protection systems should be available to provide sufficient polarisation of the critical regions in the time from initial immersion to full commissioning of the system.

iv) Impressed current systems may require back-up systems of sufficient capacity to provide or maintain the polarisation of critical regions for the periods prior to commissioning or when the system is switched off for maintenance, diver activity, or other operational requirements.

v) Design criteria, usually based on a specific average current density over a structure or parts of a structure, should recognise the effects of:

   - distribution of anodes in relation to structure geometry so as to provide adequate local current densities throughout the life of the structure;
   - the dominant depolarising effect of dissolved oxygen, the magnitude of which will increase with lowered environment temperatures and increased turbulence;
   - increased current demands during and after a storm;
   - increased corrosion rates at elevated metal temperatures;
   - reduction in available protective current as active anode materials are consumed during their operational life;
   - the possibility of microbial activity in the mud region and in internal submerged zones.

vi) The regular and frequent monitoring of steel/sea potentials preferably by a permanently installed system is a minimum performance monitoring requirement. In addition anode current and/or cathode current density monitoring may be advantageous. The location of monitoring instruments is important and should take into consideration:

- areas least likely to receive full protection in terms of either potential or current density;
- items requiring high operational integrity;
- highly stressed regions;
- areas on high strength steel structures most likely to suffer from hydrogen assisted cracking if over-protected;
- sufficient representative locations to indicate general trends of levels of cathodic protection throughout the structures.

vii) Provision should be made in the design and construction for all cathodic protection components to be adequate to withstand the mechanical aspects of all periods of the anticipated life. Anodes should be securely fixed and installed in such a way as to prevent their being damaged by wave forces, by installation work or by craft coming alongside. In particular it is necessary to consider the effects of abnormal conditions such as:

- piling activity (sacrificial anode fixings);
- storms and construction (impressed current anode cables, conduit, and monitoring systems);
- anchor damage (remote impressed current anode cables).

3.3 PROTECTION OF CONCRETE REINFORCEMENT

Concrete reinforcement should be protected by compliance with the requirements for cover, crack limits etc. Further information on the design of concrete structures is presented in OTO 2001 046.

3.4 CATHODIC PROTECTION (CONCRETE STRUCTURES)

The notes on cathodic protection in Section 3.2 also apply to the exposed steel components of concrete structures. There are also particular problems of corrosion protection for concrete structures and the following specific items should be noted:

i) When cathodic protection is applied to submerged attached or adjacent steelwork the interaction effects between this and the reinforcement or prestressing steel should be considered.

ii) The risks of enhanced corrosion of the submerged attached steel due to seawater/steel/concrete corrosion cells should be considered.

iii) Reinforcing steel should be electrically linked to the external cathodically-protected steel and the whole cathodic protection system should be designed to allow for current flow into the reinforcement.

iv) With prestressing steel it is important to avoid uncontrolled current flow which may lead to corrosion. It is important also, to avoid hydrogen-induced cracking.

Prestressing systems, including ducts and anchorages, should be designed as part of an equipotential network allowed for in the overall design of the cathodic system.

4. CORROSION AND EROSION PROTECTION OF PLANT AND EQUIPMENT

Corrosion and erosion related risks should be identified for offshore plant and equipment exposed to corrosion or erosion under all foreseeable conditions, and provision should be made for the control of these risks.

4.1 DESIGN CONSIDERATIONS

An analysis should be carried out during the design stages of plant and equipment to assess and reduce corrosion and erosion related risks. The risk of loss of containment of hazardous or pressurised fluids should be reduced to the lowest practicable level. The analysis should include (as applicable), but not necessarily be limited to, the following:

i) identification of critical items of plant and equipment;

ii) an assessment of the hazards arising from loss of containment;

iii) the nature and extent of potential corrosion and erosion mechanisms during the expected lifetime and particular service of the equipment. Operational factors which need consideration include temperature, pressure, fluid velocities, chemical composition of the contained fluid(s), sour conditions, choice of construction materials (including thickness allowance, insulation, internal cladding or lining), radius of curvature at bends, cyclic and thermal loading etc;

iv) an assessment of the effects of changing reservoir characteristics on the materials selected;

v) nature and extent of other contributory factors, for example: external loads, sand loading, vibration, fatigue, effects of lagging or insulation etc;

vi) an assessment of the proposed inhibition and corrosion monitoring methods and associated facilities, including an assessment of proposed locations, monitoring frequencies and anticipated maximum corrosion rates.

After fabrication and installation, the results of the analysis should be updated to ‘as-built’ status.

Where corrosion and erosion can be predicted in a reliable manner, appropriate management systems should be defined to ensure that its control is effectively achieved.

4.2 OPERATIONAL REQUIREMENTS (MONITORING AND RECORDING)

Management systems and procedures should be in place to ensure that corrosion and erosion risks are effectively monitored and controlled in the working environment.

Any susceptibility to corrosion or erosion related degradation attributable to the design, materials, operating conditions, composition of the contained fluids, the external environment or any other cause should be documented. Any foreseeable mode of failure and the nature of specific hazards should also be defined. Actions and contingency plans which relate to the implementation of measures for the limitation and control of corrosion and erosion should be identified.

To this end, the progress of corrosion and erosion should be monitored to a formal programme designed and, if necessary, adjusted to take into account high risk areas by increased frequencies of inspection and *vice versa*.

The frequency of inspection should be such as to give timely warning of any degradation of the system and prior indication of any requirement for remedial measure, repairs or replacements within the planned maintenance programme.

The data storage system should allow easy access to the history of corrosion and erosion related damage for all systems on the Installation and enable the cumulative effects of corrosion and erosion to be compared with the 'as-built' standard. Where practicable, historical failures on the Installation and in other relevant cases should also be stored.

As conditions change, the analysis of the system should be updated, particularly with reference to ongoing relevance of type, locations and suitability of individual monitoring systems. For example: equipment is frequently designed in a conservative manner to give a first indication of corrosion rates, say on a pipe wall, and will not necessarily exactly model the corrosion of the pipework. Where high individual or cumulative effects are recorded, the monitoring techniques should be reviewed and secondary verification of the corrosion/erosion problem obtained (eg. by ultrasonic inspection or internal inspection).

The assessment of corrosion and erosion risks is dependent on the availability of information on operating conditions of the plant or equipment for example: flowrates, temperatures, pressures, plant fluids composition, external environment etc. This information should be recorded for each plant, equipment and operating stream. Processed (ie. reduced) data should be stored with other corrosion/erosion information. Similarly, stored chemical analysis information will assist the assessment of the location, nature and severity of the corrosive environments within the plant.

Physical measurements (eg. thickness) may also be used to monitor corrosion and erosion and can provide valuable information on the performance of materials, fluid environments and measures for the control of corrosion and erosion. The physical monitoring of erosion may be critical in situations where flow velocities are high, abrupt changes in flow direction occur and where these conditions are accompanied by high fluid corrosivity.

4.3 CORROSION AND EROSION PROTECTION SYSTEM

During manufacture, fabrication, installation, maintenance, repair and inspection, care should be taken to maintain the integrity, of any protection system used. Damage to such a system should be rectified as soon as is reasonably practicable. The damage and the repair should be reported as in Section 4.2.

Welding procedures, repair methods, surface treatments and inspection procedures should include consideration of the potential failure modes in corrosive or erosive environments and the measures that can be taken to prevent or minimise the effects.

5. CORROSION UNDER LAGGING, INSULATION AND PASSIVE FIRE PROTECTION

5.1 GENERAL

The problem of corrosion under lagging etc. is related mainly to the ingress of water and may be found on installations of any age. It is not restricted to the lagging of piping and equipment and can include insulation of structural areas and areas under supports and clamps.

The design and maintenance of lagging should permit inspection and acquisition of corrosion monitoring data without affecting its ability to exclude water.

Regular checks underneath the lagging and insulation of the piping and equipment should be carried out as part of the maintenance scheme. Where the extent of corrosion damage is such that it is approaching limits allowed in the design code, or where accelerating corrosion rates are detected, the corrosion should be assessed immediately. A corrosion monitoring and recording scheme should be introduced (see Section 4.2).

Access arrangements should be provided to allow an adequate number of wall thickness measurements to be taken and the surface of the insulated surface beneath the access point to be examined. Access points should be arranged so that the watertight integrity of the lagging or insulation is not impaired.

It should be noted that:

- Corrosion may not always manifest itself directly underneath an area of lagging that is damaged or has lost its watertight integrity, but can appear some distance away from the affected area.
- Corrosion under lagging or insulation is not limited to carbon steel materials. Consideration should be given to the corrosion mechanisms that can occur with other materials.

5.2 FACTORS AFFECTING CORROSION RATES

Corrosion rates are increased by:

- the presence of mineral salts in the insulation material or introduced by water ingress;
- the absorption of water by hygroscopic insulation materials;
- entrapped water within the insulation or lagging and the effects of capillary action;
- elevated temperatures (particularly above 60°C);
- low temperature to elevated temperature cycling;
- inadequate coatings applied to the surface before it was insulated.

Corrosion rates can be reduced by the following means which should be considered during construction and renovation:

- a good quality coating system applied to the surface;
- non-hygroscopic or water-resistant insulating materials;
- watertight sealing for external cladding;
- where practicable, the removal and replacement of lagging with protective screens or cages;
- drain points installed at susceptible locations where problems have been encountered with entrapped water.

The need for retrofitting should also be considered.

Drain points can be a useful means of indicating the first signs of leakage beneath an insulated surface. Signs of leakage should be immediately investigated.

Should the use of combustible insulation or watertight sealing materials be considered, due account should be taken of the fire safety implications including the potential for smoke and toxic fume emissions, particularly in enclosed manned spaces such as accommodation, the TR and control rooms.

5.3 INSPECTING UNDER LAGGING WITH ACCESS POINTS PROVIDED

When checking underneath lagging or insulation where access has been made available, the following points should be addressed:

- Wall thickness compared to minimum design wall thickness and the original installed wall thickness;

- Surface condition. In this respect, attention should be paid to the following:
  - i) localised corrosion, particularly on the underside of pipes and equipment surfaces;
  - ii) corrosion pitting;
  - iii) adequacy of any, coatings and coating damage;
  - iv) the condition of the lagging (entrapped corrosive substances).

Note: Lagging or insulation should not be used as a substitute for a good high quality coating.

5.4 INSPECTING UNDER LAGGING REMOTE FROM (OR WITH NO) ACCESS POINTS

To assist in checking for the possibility of corrosion under lagging in areas without access points, the following are some of the techniques which might prove useful:

- Thermography (this method gives quick results and will indicate the presence of liquid in the lagging, which may give rise to corrosion);
- Neutron Back Scatter;
- Flash Radiography.

5.5 PRIORITY INSPECTION AREAS

Inspection areas should be prioritised on the basis of the severity of the consequences of failure of the system in the particular area. Piping and systems likely to receive high priority include (not in any order of priority):

- Insulated piping and systems containing flammable, hazardous or toxic materials, particularly where the system operates above ambient temperature or is subject to temperature cycling;

- Areas where the cladding shows signs of damage or the weather-proofing has lost its integrity, particularly in areas subjected to:

  i) deluge or salt water wash-down;

  ii) spray;

  iii) rainfall;

  iv) high humidity;

  v) high winds.

- Changes in direction and low points;

- Insulated systems used for essential safety, life support or emergency services.

6. SURVEYS (CORROSION PROTECTION)

Inspection of corrosion and erosion related damage or deterioration to the Installation and its plant and equipment should be included in the requirements for surveys, as should the needs for major, annual, additional and continuous surveys. While all opportunities for corrosion and erosion surveys should be used (eg. production shut-downs), routine inspection periods should be based on survey intervals which are regularly reconsidered.

6.1 PLANT AND EQUIPMENT

For offshore plant and equipment, the surveys should establish the continuing suitability of the systems and procedures upon which the management, limitation and control of corrosion and erosion depend. The planning of surveys should take into account the possibility of changes in the rate of consumption of wall thickness as inferred from the results of monitoring or due to changes in operating conditions.

The major survey should include a review of the condition of all management and systems applicable to the control of corrosion and erosion on the plant and equipment. Other surveys should confirm that suitable information is being obtained, validated and used as the basis for corrosion and erosion control management.

If, as a result of the annual survey or any additional survey, it is concluded that a more frequent survey period is appropriate, the nature and frequency of future surveys should be reconsidered.

7. MANUALS (CORROSION PROTECTION)

7.1 PLANT AND EQUIPMENT

It could be beneficial to establish a document which details corrosion risk management. Suggestions for the establishment of such a Corrosion Risk Management (CRM) Manual are presented below.

The suggested contents of a CRM Manual are:

- Details of the systems, facilities and procedures required for the management of corrosion and erosion related risks and hazards. It should be a working document, be regularly maintained and updated, and be readily accessible.
- Detailed particulars of, or reference to, materials and equipment specifications, standards, test methods and recommended practices which relate to the control and management of corrosion and erosion risks.
- Detailed plans and drawings of installed and portable systems and equipment used for detection, monitoring or control, together with their location.

Revisions or amendments to the CRM Manual may be required if there are changes to fabrications or equipment or changes in operating conditions (fluid composition, temperature, pressure etc.) which affect the control or monitoring of corrosion and erosion and associated risks.

8. REFERENCES

1. Department of Energy. Offshore Installations: Guidance on Design, Construction and Certification, 4th Edition. HMSO, Consolidated Edition, 1993 (plus Amendment No. 3, 1995). [Withdrawn 1998 by Operations Notice 27].

2. SI 1974 / 289 : The Offshore Installations (Construction and Survey) Regulations 1974, HMSO, 1974. [Revoked and has been replaced by SI 1996 / 913 – The Offshore Installations and Wells (Design and Construction etc.) Regulations, 1996 – ISBN: 0 110 54451 X].

3. Health and Safety Executive. Status of Technical Guidance on Design, Construction and Certification. Operations Notice 27. Revised and reissued, August 1998.

4. Marine Technology Directorate. Design and Operational Guidance on Cathodic Protection of Offshore Structures, Subsea Installations and Pipelines. MTD Publication 90/102, 1990. ISBN: 1 870 553047.

5. NACE International: RP-01 76 : Control of Corrosion on Steel Fixed Offshore Platforms Associated with Petroleum Production, March 1994.

6. British Standards Institution. CP 1021 : 1973 Code of Practice for Cathodic Protection. [Withdrawn and replaced by British Standards Institution. BS 7361 : Part 1 : 1991 – Cathodic Protection – Code of Practice for Land and Marine Applications].

7. FIP (Federation Internationale de la Precontrainte) : FIP/6/1 Recommendations for the Design and Construction of Concrete Sea Structures 4th Edition, 1985. [This document provides recommendations only and should be used with caution].

8. Det Norske Veritas. TNA 703 Technical Note : Cathodic Protection Evaluation. [This is now Det Norske Veritas. RP D401 – Cathodic Protection Design, 1993].

Printed and published by the Health and Safety Executive
C0.50 06/02

HSE BOOKS

MAIL ORDER
HSE priced and free
publications are
available from:
HSE Books
PO Box 1999
Sudbury
Suffolk CO10 2WA
Tel: 01787 881165
Fax: 01787 313995
Website: www.hsebooks.co.uk

RETAIL
HSE priced publications
are available from booksellers

HEALTH AND SAFETY INFORMATION
HSE InfoLine
Tel: 08701 545500
Fax: 02920 859260
e-mail: hseinformationservices@natbrit.com
or write to:
HSE Information Services
Caerphilly Business Park
Caerphilly CF83 3GG

HSE website: www.hse.gov.uk

OTO 2001/011

£10.00

ISBN 0-7176-2383-1

9 780717 623839