



GUIDANCE NOTES ON

CATHODIC PROTECTION OF OFFSHORE STRUCTURES

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Foreword

Cathodic protection in conjunction with protective coatings is a common method used to protect immersed parts of steel surfaces from corrosion. These *ABS Guidance Notes on Cathodic Protection of Offshore Structures* offer detailed recommendations on cathodic protection for offshore structures.

Traditional seagoing vessels dock at regular intervals, but offshore structures such as Floating Production Storage and Offloading structures (FPSOs) are stationary and are in continuous operation for long periods of time. Therefore, the design of the corrosion protection for a 15-year or longer service life of a floating offshore structure is considered in these Guidance Notes.

Some Floating Production Installations (FPIs) have hull designs similar to oil tankers, especially those converted from oil tankers. Others are designed and built as floating production platforms. Cathodic protection systems are to consider the structure to be protected as a whole as well as individual components which are attached to the structure.

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SECTION 1 General

1 Scope

These Guidance Notes define the best practice and design recommendations for corrosion protection of offshore structures using cathodic protection (CP) systems, and provide guidelines for cathodic protection design, installation, and maintenance. The basic approach to the cathodic protection design of the offshore structures is to combine cathodic protection with an effective coating system for the underwater surfaces to be protected. These Guidance Notes can be applied to both coated and bare submerged surfaces.

These Guidance Notes mainly cover the cathodic protection of the submerged external surfaces of floating offshore structures, such as barges, jack-ups, semi-submersible platforms, storage tankers, and buoys, which are static during their normal operating condition. Fixed platforms and concrete platforms are not covered in this document.

These Guidance Notes cover the submerged areas of appurtenances and openings, mooring lines attached to the structure, sea chests and water intakes up to the first valve. The internal surfaces of flooded compartments/ballast tanks are also considered.

These Guidance Notes do not cover the cathodic protection of ships, pipelines, subsea casings, subsea manifolds/flow lines/jumpers/umbilicals, risers and cables. The cathodic protection of ships is covered by the *ABS Guidance Notes on Cathodic Protection of Ships*.

These Guidance Notes do not cover corrosion control of the internal portions of wells, piping, and associated equipment that may be installed on or attached to structures. Underwater pipelines and pipeline risers are specifically excluded from these Guidance Notes.

These Guidance Notes do not cover safety and environmental protection aspects associated with cathodic protection. The relevant national or international regulations should apply.

3 Materials

These Guidance Notes consider structures fabricated principally from carbon manganese or low-alloy steels. Hulls primarily made of other materials such as aluminum alloys, stainless steels, or concrete are not covered in these Guidance Notes. P1

Because some parts of the structure may be made of metallic materials other than carbon manganese steels, the cathodic protection systems should be designed to exert complete control over any galvanic coupling and should minimize risks due to hydrogen embrittlement or hydrogen-induced cracking.

Cathodic protection can affect the corrosion fatigue properties of the structure. In general, cathodic protection can have following effects on the fatigue:

- Cathodic protection at typical potential values tends to improve the fatigue performance of steel in seawater.
- The rate of propagation of fatigue cracks may be accelerated in some steels with highly negative cathodic protection potentials. Fatigue crack growth data may be used to establish whether highly negative potentials are significant.

This document does not include any consideration of possible effects of cathodic protection on the fatigue life of the hull.

5 Offshore Corrosion Zones

5.1 General

These Guidance Notes are applicable to the whole submerged zone in seawater and saline mud which can normally be found where the floating structure is anchored, moored or moving. It is also applicable to appurtenances which may be in contact with muds (e.g., chains, spudcans).

To simplify corrosion control of structural steel of offshore structures, offshore external structures can typically be divided into three (3) corrosion zones: Atmospheric Zone, Splash Zone and Submerged Zone. In addition, a Mud Zone is considered for jacking or self-elevating structures.

5.3 Atmospheric Zone

The atmospheric zone of an offshore structure extends upward from the splash zone. It is exposed to sun, wind, spray, and rain. Corrosion in this zone is typically controlled by the application of a protective coating system.

5.5 Splash Zone

The splash zone is intermittently wetted by waves, wind-blown water spray, and tidal action (including the tidal zone). In the Gulf of Mexico, the splash zone is typically about 2 m (6 ft). In Cook Inlet, Alaska, this zone is about 9 m (30 ft). The North Sea splash zone can extend to 10 m (33 ft) during winter storms. Methods for controlling corrosion in the splash zone include both coatings and cathodic protection (CP). Cathodic protection as a supplement to protective coatings can be used in a splash zone that is intermittently submerged. Cathodic protection is only effective when the immersion time is sufficiently long enough for the steel to become polarized. Cathodic protection does not provide protection to the portions of the splash zone that are wet due to sea spray or infrequent immersion.

5.7 Submerged Zone (External Areas)

The submerged zone (external areas) is the zone below the splash zone and includes any portion of the structure below the mudline. Corrosion control of the submerged zone can be achieved through cathodic protection or cathodic protection in conjunction with coatings.

5.9 Submerged Zone (Internal Areas)

The submerged zone (internal areas) are the internal surface areas of tanks and flooded compartments. Corrosion normally is negligible in compartments that are sealed and have no contact with either the atmosphere or seawater. Whenever possible, the design should provide for sealed compartments.

Some structural members are flooded and remain flooded for the life of the structure. To prevent internal corrosion, the flooding valves should be closed after flooding to isolate the flooded chambers from the air, and fresh water should be used if possible. In compartments where circulation of seawater is possible, provisions should be made to reduce internal corrosion. Cathodic protection or a combination of cathodic protection and coatings should be used. Cathodic protection is not effective for gas phase parts of tanks and compartments, and these should be coated internally where condensation may occur. The use of impressed current systems in these compartments should be avoided due to the development of toxic and corrosive chlorine gas at the anode and possibly flammable quantities of hydrogen gas at the cathode.

In flooded compartments with a source of organic nutrients, bacterial growth may generate organic acids, carbon dioxide (CO₂), and hydrogen sulfide (H₂S) that can cause corrosion. Bacteria-related corrosion can be controlled by the use of internal cathodic protection, coatings, and microbicides.

7 Corrosion Control Considerations

7.1 Structure Design Considerations

For better corrosion control, the following should be considered:

- i) Tubular members should be used wherever possible for truss structures. Channels back-to-back and I beams are difficult to protect from corrosion and should not be used for construction.
- ii) All weld joints should be continuous. If lap joints are used, both edges should be continuously welded. Skip and tack welding should not be used. Bolted and riveted fittings should be avoided.
- iii) Critical locations of structures, their welds and the heat-affected zone (HAZ) may be stress-relieved to reduce the likelihood of fatigue or corrosion fatigue failures.
- iv) Piping, such as grout lines, well cutting lines, discharge lines, water supply casings, well casing conductors and pipeline risers can cause shielding and interfere with the flow of cathodic protection current if clustered around a large structural member. Piping/lines not needed for continuous operations should be removed or relocated to avoid cathodic protection shielding. A minimum clear spacing of 1.5 diameters of the smaller pipe should be provided.
- v) All steel to be protected should have electrical continuity with the cathodic protection system (preferably by welded contact). This electrical continuity should be provided for the lifetime of the structure. Well casing conductors should be electrically connected to the structure.
- vi) Corrosion rates below the mudline are considered to be low. However, mudline corrosion can be significant for structures with long lifetimes, and all mudline members should be properly connected to the cathodic protection system.

7.3 Piping System

Piping, valves, submerged pumps, and other special equipment should also be protected from corrosion by cathodic protection system, particularly when different metallic materials are used.

7.5 Mooring Lines

For floating systems, there are two basic mooring configurations: catenary mooring and taut mooring.

Conventional composite chain and steel wire rope catenary mooring systems are being used successfully on floating systems in water depths up to 1000 meters (3280 ft). However, in depths beyond 1000 meters (3280 ft), semi-taut and inverted catenary mooring arrangements introduce buoyancy into the mooring line combination to reduce the vertical load of the mooring line.

The corrosion protection of all components of the mooring lines should be considered during the design phase so that the moorings are not compromised by corrosion damage. The components include fairleads, chain connectors, chain and wire ropes. It should be noted that various mixed metallurgy can result in localized galvanic corrosion.

The cathodic protection current draining through mooring lines may need additional anode weight for the cathodic protection systems on the hull to which the mooring lines are attached.

For mooring lines and anchors, bacterial corrosion in the bottom parts exposed to seabed sediments is to be evaluated with consideration for the use of cathodic protection, coating, or corrosion allowance.

7.5.1 Chains

A corrosion allowance is provided for long-term service of chains. A higher corrosion allowance should be provided in the splash zone. The wear could be substantial due to chain handling. Many permanent floating production units require minimal handling of the mooring systems.

It has been shown from experience that cathodic protection for the hull structure is also effective for chains extending about 30 to 60 m (100 to 200 ft) from the structure. The length depends on the chain connection to the structure, the size of the chain, and the line tension. Galvanic coatings or protective coatings are also used for corrosion protection and fatigue improvement of the chains.

7.5.2 Wire Ropes

The large diameter spiral strand rope commonly used on offshore structures normally has its own corrosion protection scheme. The scheme may include blocking compounds, sheaths, sacrificial anode strands and galvanic coatings on the strands.

Wire ropes made from galvanized wires, with an outer extruded corrosion protection jacket of polyurethane, polyethylene, or a similar material, are usually used. Grease injection is used for lubrication and to prevent water entrapment. Sacrificial zinc wires may be included. Hydrogen effects should be evaluated as part of any cathodic protection of the ropes due to the very high strength of the wires used. It is important to confirm that there is adequate anode material and a good quality coating on the wire rope connectors.

9 Personnel

Personnel responsible for the design, testing, measurements, monitoring, supervision of installation, supervision of operation, supervision of maintenance, and inspection of cathodic protection systems are to have the necessary experience and qualifications in cathodic protection to competently perform their tasks. Personnel are to be trained and certified to achieve and demonstrate the necessary competence levels for the tasks undertaken.

EN 15257 provides a suitable method of assessing and certifying the competence of cathodic protection personnel.

11 Normative References

The following documents, in whole or in part, are normatively referenced in this document:

EN 12473	General principles of cathodic protection in seawater
EN 12496	Galvanic anodes for cathodic protection in seawater and saline mud
EN 13509	Cathodic protection measurement techniques
EN 15257	Cathodic Protection – Competence levels and certification of cathodic protection personnel
EN 50162	Protection against corrosion by stray current from direct current systems
EN 16222	Cathodic protection of ship hulls
EN 13173	Cathodic protection for steel offshore floating structures
ABS	<i>Guidance Notes on Cathodic Protection of Ships</i>

13 Definitions and Acronyms

13.1 Definitions

The following terms and definitions are used in this document:

Anode: The corroding part of an electrochemical corrosion cell. It can be a sacrificial anode or impressed current anode used in cathodic protection.

Cathode: The non-corroding or protected part of an electrochemical cell.

Cathodic Protection (CP): Cathodically protecting a metal surface from corrosion by using sacrificial anodes or impressed current anodes.

Coating System (protective coating system): The entirety of the multiple layers of coating materials applied in a certain sequence. Each layer serves its own special purpose. The combination of these different layers of coatings or paints ideally leads to the best solution possible to protect the substrate surface from corrosion. Any substrate surface treatment is also considered to be part of the coating system.

Corrosion Rate: The rate, usually in mm/year (MPY), 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”.)

Epoxy: A common resin (binder) type in paints or coatings for marine use. Epoxies are normally of two component types, epoxy resin (A component) chemically reacted with a hardener (B component, e.g., amine), resulting in a relatively hard film.

ISO 8501-1 Sa 2½: An ISO surface cleanliness pictorial standard detailing very thorough blast cleaning. When viewed without magnification, the surface shall be free from visible oil, grease and dirt and from scale, rust, paint coatings and foreign matter. Any remaining traces of contamination shall show only as slight stains in the form of spots or stripes. Sa 2½ corresponds to NACE Grade No. 2 (near white) and SSPC grade SP 10 (near white).

Shadow Effect: Areas to be protected are not “seen” by the anodes of the cathodic protection system installed. More anodes may be needed for complex structures with consideration of the *Shadow Effect*.

Underwater Hull: Part of the hull below the light waterline.

13.3 Acronyms

<i>AC</i>	Alternating Current
<i>Ag</i>	Silver
<i>AgCl</i>	Silver Chloride
<i>CP</i>	Cathodic Protection
<i>DC</i>	Direct Current
<i>DFT</i>	Dry Film Thickness
<i>EMF</i>	<i>Electromotive Force</i>
<i>FPI</i>	Floating Production Installation
<i>FPSO</i>	Floating Production Storage and Offloading
<i>HAZ</i>	Heat Affected Zone
<i>HISC</i>	Hydrogen-induced Stress Cracking
<i>ICCP</i>	Impressed Current Cathodic Protection
<i>IMR</i>	Inspection, Maintenance, and Repair
<i>IR Drop</i>	Voltage drop across any resistance, which is the product of current (I) passing through resistance and resistance value (R)
<i>MGPS</i>	Marine Growth Prevention Systems
<i>PWHT</i>	Post Weld Heat Treatment
<i>ROV</i>	Remotely operated vehicle
<i>SACP</i>	Sacrificial Anode Cathodic Protection
<i>Zn</i>	Zinc



SECTION 2 Design Criteria and Recommendations

1 General

A cathodic protection (CP) system uses galvanic anodes, an impressed current system, or a combination of both. The objective of cathodic protection is to control corrosion of metallic surfaces which are in contact with electrolytes (such as seawater).

The cathodic protection system should provide sufficient and well-distributed currents (or well-distributed anodes) to protect each part of the structure and appurtenances so that the potential of each part of the structure can be polarized to be within the limits given by the protection criteria (See Subsection 2/7) over the design life. Special consideration should be given to areas such as chains, water intakes, thrusters, and sea chests.

3 Design Life

The design life of a cathodic protection system for the submerged hull of a floating offshore structure is normally specified by the owner. Either the whole design life or dry-docking interval(s) should be considered. The design life should further take into account any period of cathodic protection active time prior to commissioning of the protected structures.

Maintenance, repair and retrofitting of cathodic protection systems for offshore structures are generally very costly and sometimes impractical. It is therefore normal practice to apply at least the same anode design life as for the protected structure with minimal maintenance/retrofitting requirements. However, in certain circumstances planned retrofitting of sacrificial anodes may be an economically viable alternative to the initial installation of very large anodes. This alternative should then be planned such that necessary provisions for retrofitting are made during the initial design and fabrication.

5 Environment

The design of the cathodic protection systems for the offshore floating structures should consider the anticipated service conditions at the location installed or moving to, such as water salinity, temperature, and ice conditions.

Because the potential criteria provided in Subsection 2/7 is a function of the temperature, dissolved oxygen content, salinity, water velocity, and water conductivity, the seawater properties should be established (see EN 12473). Unlike ships, the static conditions are normally considered for the floating offshore structures because the durations when dynamic conditions prevail are generally negligible; even some loop current may also be considered.

7 Potential Criteria of Cathodic Protection

7.1 Protection Potential

The cathodic protection criteria given in Section 2, Table 1 of the *ABS Guidance Notes on Cathodic Protection of Ships* should be referred to for offshore structures. As indicated in the Table, the accepted criterion for protection of carbon steels or low-alloy steels in aerated seawater is a protection potential of -0.80 V or more negative measured with respect to the Ag/AgCl/seawater reference electrode. In the case of mild steel with active sulfate-reducing bacteria (generally in anaerobic conditions), the potential for protection is -0.90 V (instead of -0.80 V) with respect to Ag/AgCl/seawater reference electrodes. For other circumstances, the potential for corrosion control can be estimated using the Nernst equation.

It is important to emphasize that with increasing negative potentials, there may be an adverse effect on fatigue properties and a risk of hydrogen embrittlement of susceptible steels. The polarized potential should not be more negative than -1.10 V (Ag/AgCl (Seawater)) for carbon steels and austenitic stainless steels. Section 2, Table 1 of the *ABS Guidance Notes on Cathodic Protection of Ships* also provides negative limits for various materials as a recommendation with further descriptions of the detrimental effects from the cathodic protection, which are summarized as follows for applications in floating offshore structures:

- i) Cathodic protection can cause the formation of hydroxyl ions and hydrogen at the steel surface being protected. The formation of these products may cause disbonding of non-metallic coatings at the metal/coating interface. Coating systems compatible with cathodic protection should be considered.
- ii) Cathodic protection can eliminate the anti-fouling properties of copper-based alloys in seawater.
- iii) For subsea fasteners connected to a cathodic protection system, hydrogen should be always be considered. It is therefore critical to select appropriate materials for subsea fasteners.

Carbon steel fasteners with increasing strength have increasing susceptibility to hydrogen. 350 HV hardness as an upper limit is recommended for subsea fasteners exposed to cathodic protection. Bolts with strengths up to 720 MPa SMYS are typically considered appropriate for cathodic protection compatibility.

Bolts fabricated from AISI 316 stainless steel are typically compatible with galvanic anode cathodic protection.

- iv) Austenitic stainless steels and nickel based alloys: Those materials in the solution-annealed condition generally are considered appropriate for cathodic protection compatibility.

Moderate cold work of these materials does not cause an HISC issue except for UNS S30200 (AISI 302) and UNS S30400 (AISI 304) stainless steels.

Hardened austenitic stainless steels with hardness higher than 350 HV are generally not good candidates to receive cathodic protection.

- v) Ferritic and ferritic-pearlitic steels: Materials with a specified minimum yield strength (SMYS) up to 500 MPa have proven compatibility with marine cathodic protection systems. All welds should not have hardness greater than 350 HV.
- vi) Martensitic carbon and low-alloy steels: Materials with an actual yield strength of about 700 MPa and a hardness about 350 HV could fail under cathodic protection protection.

Untempered martensite with the specified minimum yield strength (SMYS) greater than 500 MPa is especially prone to hydrogen-induced stress cracking (HISC). Welding of materials susceptible to martensite formation should be followed by post weld heat treatment (PWHT) to reduce hardness in the heat-affected zone (HAZ) and residual stresses from welding. All welds should not have hardness greater than 350 HV.

- vii) Ferritic-austenitic (“duplex”) stainless steels: These materials are susceptible to HISC regardless of SMYS or specified maximum hardness.

Welding may cause increased HISC susceptibility in the weld and the HAZ. Ferrite content rather than hardness of the welds may be controlled to maximum 60 to 70%.

Forgings are more prone to HISC than wrought materials.

Small diameter cold bent pipes, used as production control piping for subsea installations, typically have a good cathodic protection compatibility. However, the design should employ a qualified coating system and prevent local plastic yielding.

- viii) Copper and aluminum-based alloys are generally immune to HISC, regardless of fabrication modes.
- ix) For high-strength titanium alloys, special qualification testing should be considered due to lack of documentation.

7.3 Cathodic Protection Evaluation

7.3.1 General

The protection criteria and effectiveness of cathodic protection systems should be confirmed by direct measurement of the potential of the structure. However, visual observations of progressive coating deterioration and/or corrosion are indicators of possible inadequate protection. Steel plate thickness gauging can measure deficiencies in corrosion protection.

Storm waves or strong tides can produce high water velocities that tend to depolarize the structure. Depolarization is less likely to be a problem for well-polarized structures with well-formed calcareous deposits or for coated steel structures.

All potential measurements on the structure should be made before removal of marine growth because the removal process could depolarize the steel.

7.3.2 Reference Electrode

The Ag/AgCl/seawater reference electrode potential is somewhat affected by the resistivity (caused by the chloride content) of the seawater in which the electrode is immersed. If the resistivity is known to differ appreciably from that of ordinary seawater [20 ohm-cm at 20°C (7.9 ohm-in at 68°F)], the electrode reading should be corrected.

Other standard reference electrodes, such as high-purity zinc electrodes, may be used to substitute the Ag/AgCl/Seawater. Refer to 2/3.4 of the *ABS Guidance Notes on Cathodic Protection of Ships* for more details.

7.3.3 Potential Measurements

Potential measurements should be made with the reference electrode and a high impedance (minimum 10 MΩ) voltmeter. The reference electrode should be located in the seawater away from anodes and as close as practicable to the structure to minimize voltage drops. Some measurements should be taken in areas of greatest shielding in evaluating the protective level of a structure.

Consideration should be given to voltage (IR) drops other than those across the steel/water interface when structure potential data are evaluated. Changes in water resistivity or temperature variation can affect the voltage drop.

In impressed current systems, under conditions involving high-resistivity water or high current density, the voltage drop may be excessive. Potential measurements taken immediately after turning off the rectifier(s), called Instant-Off measurements, may provide useful information by eliminating voltage drop in the water.

For galvanic anode protection systems, the included voltage drop is generally not significant in ordinary seawater if the reference electrode is placed close to the structure. The voltage drop may become significant in brackish waters. In such cases, it may be necessary to use interruptible coupons or other IR correction techniques to determine the true potential of the metal surface.

The methods of measuring potentials can be involved in different ways:

- i) The reference electrode can be suspended freely in the water from a designated location on the structure. The location of the electrode may not be known because of drift resulting from water currents. It may not be appropriate for the identification of problem areas on protected structures. This method is used to assess the general condition of the cathodic protection system.
- ii) The reference electrode may be run down along a guide wire for control of its location. The guide wire may be permanently installed on the structure, or it may be temporarily installed with the aid of a heavy weight to anchor the guide wire at the bottom. If the guide wire is metallic, it should be electrically isolated from the structure.