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The New Risk Perspective in Corrosion Management

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Abstract

This paper describes a risk-based approach for corrosion management of offshore floating structures. The objective of this approach is to reduce the risk of corrosion related failures, reduce the associated downtime, while improving the cost-effectiveness of corrosion inspection and maintenance.

Corrosion is increasingly a significant challenge to the offshore industry and attributed to: an aging worldwide offshore fleet; assets being kept in operation for prolonged periods of time; units operating beyond their original "design basis"; and newer larger vessels in deeper, harsher environments with less opportunity for ship yard repair. Corrosion is particularly detrimental to the integrity of the unit, and if not managed properly will increase maintenance costs and downtime costs, possibly reducing the useful operational life of the unit. Although, there are several existing offshore corrosion design standards, experience still reveals a number of assets in poor and critical condition due to corrosion.

Clearly there is a need for a holistic approach on corrosion management during the full operational life of the asset. The presented methodology is based on the principles of ISO 31000 (Risk Management - Principles and Guidelines) to provide a solid consistent framework for corrosion management. The risk-based corrosion management process for offshore structures described in this paper consists of five (5) basic steps: Pre Assessment; Screening and Risk Ranking; Detailed Examination; Remediation and Repair; and Life Cycle Management.

Adopting the described risk based corrosion methodology will provide confidence to the operators and demonstrable evidence to key stakeholders that corrosion is being managed on their assets. It will account for life extension, reduce the risk of corrosion failure, and lower the cost of inspection and maintenance.

Introduction

Sixty percent (60%) of the world's offshore fleet are past their theoretical design age of 20 years, while the demand to use offshore installations beyond the theoretical design age is growing. Consequently, there is an urgent need to manage material deterioration, (i.e. fatigue cracking and corrosion), and to demonstrate to the rig owners and stakeholders the ongoing integrity and safety of those aging rigs.

Existing rules and standards typically address the design phase of a project. They are used to predict the expected general aging effects for a given region to enable selection and design of the final protection systems (e.g. coating, cathodic protection or permitted wastage). For example corrosion control is covered in:

- DNV Offshore standards OS-C401, OS-C101, OS-C103, OS-C104, OS-C107 covering corrosion control, fabrication and installation of corrosion protection systems, i.e. coatings, anodes, and impressed current cathodic protection systems (ICCP). To name some specific requirements:
    - In general, corrosion protection systems should prevent structural deterioration over a rig's operating life.
    - The Rules assume that hard coatings are supplemented by cathodic protection, but alternatives are not excluded.
    - The Rules state that the Owner is responsible to maintain the unit in accordance with the design.

- The IMO (Performance Standard for Protective Coatings for Dedicated Seawater Ballast Tanks) Requirement issued on 1st July 2009 states that all ballast tanks must have type approved coatings and a technical file for the coatings to be approved.

However, recent inspection experiences have revealed a number of rigs with severe corrosion, general lack of reporting and poor maintenance, attributed to either a greater deterioration than expected or due to the asset operating for longer than expected. Clearly there is the need for a holistic, lifecycle approach to corrosion management of offshore structures, and to demonstrate to the rig owners and stakeholders the ongoing integrity and safety of those aging structures. To be effective, such an approach should reduce risk of failures, optimize maintenance and inspection cost, support the continuation of the unit's operations and be flexible enough to account for extended life operation. Finally the corrosion management approach needs to be "just good enough" to make sense on a financial and risk basis.

Objective

The object of this paper is to describe a practical risk-based approach to corrosion management of floating offshore assets, which is based on the principles of ISO-31000 'Risk Management – Principles and Guidelines'. The paper describes an approach to corrosion management to improve the cost-effectiveness of corrosion inspection and treatment of floating offshore vessels in operation, and at the same time reduce the risks of incidents and down time. This approach is elaborated in DNV's Recommended Practice DNV-RP-C302, which provides practical guidance and support for the rig superintendent and/or surveyor to inspect and assess the condition of the structure as related to corrosion and corrosion control.

The 5-step approach

The risk-based corrosion management approach is based on 5 practical steps, as shown in Figure 1 is closely linked to the risk management process in ISO-31000. The steps are elaborated below.

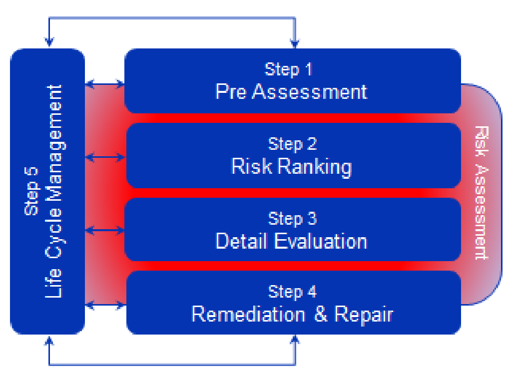

Figure 1 - Risk Based Corrosion Management Approach

Step 1 – Pre Assessment

The pre-assessment is an important first step in the risk based corrosion management process. While the risk assessment of corrosion failures is the main theme of the paper, it is important to retain relevance and be framed within the context of an overall corporate risk philosophy. This will include:

- Company risk tolerance
- Company risk culture
- Operating area specific elements (legislation/ political situation/ incident history)
- Requirements, legal obligations due to contracts with ordering party.

This first step identifies the threats and consequences of failure due to corrosion, as well as the threat severity, and establishes the specific setting for risk management. During this first step, historic information will be collected and potential threats will be identified. Specifically, corrosion threats will be identified by determining potential causes for coating breakdown, cathodic protection failure and corrosion. The historical corrosion properties (coating records, cathodic protection readings, etc.) are reviewed with reference to the original design documentation in order to establish causes for susceptibility to corrosion. *Consequences* can thereafter be defined in terms of health and safety, environment, and financial/reputation aspects. The risk setting includes an assessment of the consequences of corrosion failures in terms of health & safety, environment, finance & reputation, and to determine the tolerances to these.

The threat and consequence assessments provide input to the risk that can be incorporated into a Corporate Risk Assessment Matrix, such as shown in Figure 2, so that the risk can be assessed with respect to the corporate risk tolerance, see Step 2.

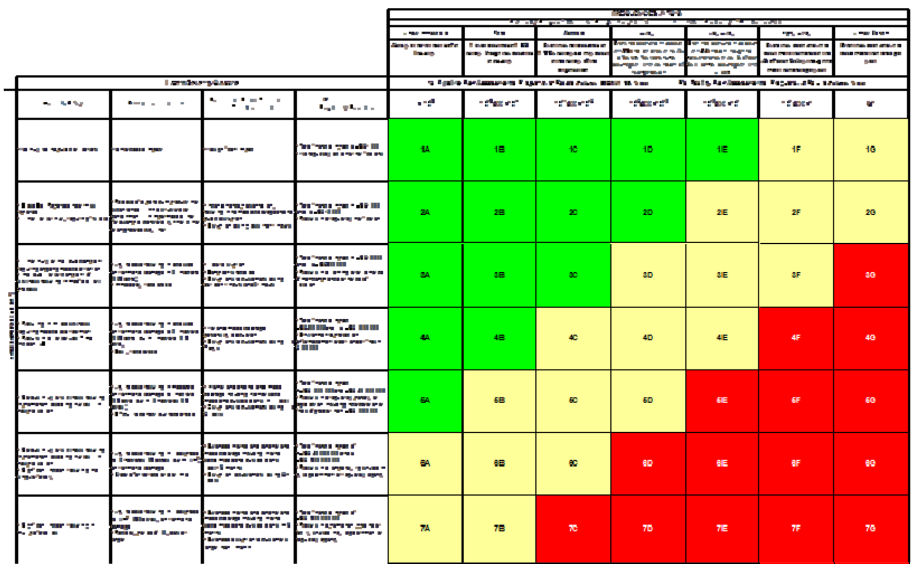

Figure 2 – Typical Corporate Risk Assessment Matrix

Typically the threats can be grouped according to 4 general exposure zones of the floating asset, i.e.:

- Submerged– Underwater structures below the splash zone
- Splash zone – often a 9m band around water line
- Topside structures – atmospheric, above the splash zone
- Tanks and internal structures.

Risk Identification for Different Exposure Zones

Submerged

Continuously submerged structures are protected against corrosion by a combination of compatible coatings and cathodic protection (CP); this is the only external zone where CP is a viable option to protect against corrosion. Compatible in this context means that once coating damage or deterioration has occurred, the CP system should still be able to function. During the pre-assessment, mechanisms for coating breakdown and corrosion are determined by collecting and reviewing CP and coating history and by reviewing the original CP design. The type of CP (impressed current or sacrificial anode) is determined, as well as the location and age of the anodes. The historic survey and inspection data are reviewed, and gaps in the data are identified.

Splash zone

For a floating unit with a constant draft, the splash zone is defined in DNV-OS-C101 as 5 meters above and 4 meters below the draft. The splash zone is one of the most aggressive marine environments, because of exposure to fully aerated seawater, UV radiation, repeated wetting and drying and possibly salt build up. If left unchecked, corrosion in this zone can occur at a rapid rate, causing severe localized or general wall loss. Since the upper splash zone (above the load waterline) is not fully and continuously immersed, cathodic protection cannot protect it, consequently coatings and corrosion allowance of the steel wall are the only barriers to corrosion. During the pre-assessment stage, design, coating, and historic information are collected. The required information includes type of coating, application records, corrosion history, failure history and maintenance history. If locations of coating degradation or corrosion have been historically recorded, these locations are mapped for future reference, and distribution and severity of corrosion damage is noted.

***Topsid*e**

Topside corrosion threats can occur anywhere above the splash zone. Due to the complexity and of the topside there are a greater range of consequences and associated risk. Topsides include:

- Primary structures
- Secondary structures
- Process equipment and piping
- Safety and emergency equipment.

The consequence of corrosion failure for the topside can include environmental, financial, operational, health and safety and loss of reputation. Coatings are the only cost-effective means to control atmospheric corrosion on the topside of structures. Most structures are built of carbon steel, but in special cases corrosion resistant alloys, such as stainless steels are used. Topside coatings must be flexible and resistant to UV radiation. During the pre-assessment, historical information such as type of coating, dry film thickness, application, and damage/maintenance records are compiled. Any information regarding distribution and severity of coating damage or corrosion is mapped for use in the second step. In general, the following corrosion conditions are considered in determining the specific threats of topside corrosion:

- Corrosion often starts in areas of coating damage, and areas where the coating can be of poor quality e.g. weld seams, edges, and notches.
- Stress and strain caused by overloads, reductions in steel dimensions as a result of corrosion, dents, wear, repair work, etc., may produce damage to coatings.
- Stresses and vibration may result in increased corrosion and cracks.
- Welds or heat-affected zones (HAZ), where coating may be of poor quality as a result of poor pretreatment or where welding work has been done after the coating has been applied and not properly repaired
- Complicated shaped structures with poor access, which make it difficult to inspect or to provide efficient protection, are particularly liable to suffer from undetected corrosion.
- Horizontal surfaces or areas that are not satisfactorily drained or where deposits of foreign matter are present, may suffer significant corrosion.
- Steel surfaces hidden under thermal isolation or isolating materials used for fire protection.
- General or uniform corrosion over a long period of time can have serious consequences for the structural integrity of topside structures.

Tanks and Internal Structures

Corrosion threats from internal surfaces such as ballast tanks, chain lockers, oil tanks, pump rooms, and void tanks are subject to all three exposure zones, i.e. submersed, splash and atmospheric. Because of limited accessibility and often more corrosive environments, tanks and internal structure pose a serious corrosion threat. The threat level depends on the location of the tanks, i.e. inside or outside, their contents and the exposure zone.

Ballast tanks generally pose the highest threat, because they contain (often contaminated) seawater, which is at varying levels inside the tank. These tanks require a combination of coating and cathodic protection to control corrosion in locations where the tanks are submerged. Sacrificial anode CP is exclusively used in this case, because of the changing water levels and because of potential hydrogen evolution impressed current CP in confined spaces.

When identifying threats and consequences, specific attention must be paid to the areas subject to:

- Wet and dry conditions (under-deck and shear strakes), since those area are most prone to coating breakdown and corrosion, particularly when they are wet and exposed to the atmosphere. Horizontal surfaces (e.g. tank top), where the buildup of sediment, sludge and other material can exacerbate the corrosion process.

Additional conditions to be considered include the following:

- Long spans of flexible stiffeners may allow sufficiently high deflections that disbond coatings, exposing the steel accelerating the corrosion.
- High flow rates at rebates or near inlets and outlets can result in local erosion and increased corrosion. Of particular concern is the presence of sand particles in the ballast water.

Step 2 – Screening and Risk Ranking

Risk screening is the practical extension of the data gathering of Step 1, completing the establishment of the current status in Step 1 by conducting visual risk assessments of the entire offshore installation. Where visual assessment is not possible, other methods to establish the corrosion threat, such as corrosion and CP modeling, may be used. The corrosion threats and consequences are transformed to risk and placed in the Corporate RAM. The outcome of this analysis provides input to a risk assessment process to identify locations for detailed inspection.

The screening may consist of one or more of the following elements:

- General visual inspection of the whole unit and available tanks, noting coating breakdown location and corrosion scale and anode condition
- Quantitative readings from monitoring that is already in-place and functioning (e.g. electrochemical potential reading of the impressed current CP system)
- Available footage from ROV.

Including more elements in this phase will improve the confidence in the risk ranking results.

Risk Screening for Different Zones

Submerged

A possible screening for the submerged structures is based on the standard electrochemical potential and current distribution grid, which are routinely recorded. The electrochemical potential measurements taken at prefixed locations and at different depths around the submerged structure could be used to create actual potential and current (density) maps as illustrated in Figure 3. Superimposing these onto earlier collected- or generated potential and current (density) maps could identify actual hot spots, where possible coating damage exists and corrosion is likely to occur. The example below shows a Finite Element model of a floating structure, where high current densities indicate coating failures and possible high corrosion rates underneath the coatings.

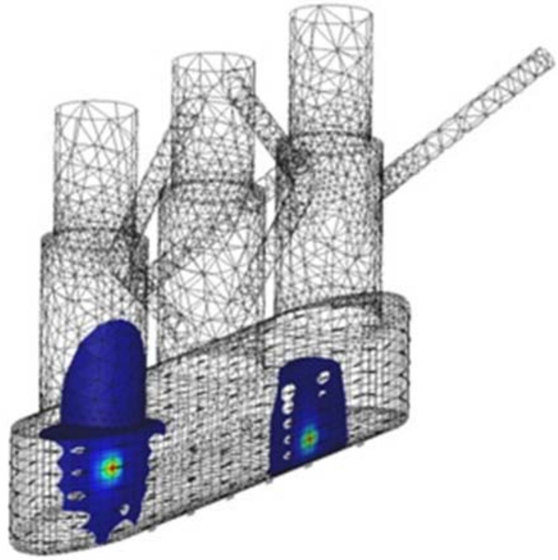

Figure 3 - A Finite Element Model of a Pontoon of a Floating Rig, Showing High Current Densities Indicating Coating Failure

Splash Zone
The screening for the splash zone includes visual inspection and photographic recording with a specific focus on those locations that were identified as having specific threats or consequences in Step 1. Otherwise, the visual/photographic inspection of primary and secondary structures exposed to the splash zone is global in nature and is conducted from a distance. The location where visual/photographic examination is conducted should be recorded such that in later steps the exact location of specific observations can be found. The location is identified by detailed description, or by painting on the structures. The photographically recorded coating damages and corrosion should be compared with historic inspection and maintenance data. The results of this analysis will confirm the threats and consequences, and are used to calculate the risk levels for the splash zone.

Topside
The screening of topside structures consists of a general visual inspection and photographic recording of coating damage and corrosion to confirm conclusions reached during Step 1. The scope of the general inspection depends on the historic inspection and maintenance records that were collected. The areas to be addressed are shown in the Table below.

Primary Structures	Secondary Structures	Process Equipment and Piping	Safety and Emergency Equipment
• Top section of the columns and braces; ship hull • Structural topside braces • Main deck and helicopter deck • Control room and control room structures • Drill rig • Cranes	• Control room and accommodations • Walkways and stairs • Communication systems	• Pressure vessels and piping • Storage tanks and vessels • Sump systems	• Firefighting systems including waterlines and pumps • Escape systems (life boats/escape modules as well as the launch systems) • Gas monitoring systems • Alarm systems

Table 1 – Topside Components and Structure that Require Inspection

Tanks and Other Internal Structures
The screening for tanks and other internal structures may consist of visual inspection of the protective coatings and corrosion and inspections of the sacrificial anodes. As a supplementary alternative, the electrochemical potential and current distribution grid as discussed for the submerged zone may be used.

The condition of the sacrificial anodes indicates areas which require close inspection. Specific features to note on the sacrificial anodes are metal loss and the degree of uniformity in metal loss. Note that sacrificial anodes must not be painted. A general guideline for replacing sacrificial anodes is that the anodes must be replaced when an estimated 60% metal loss is achieved. Replacement is also required if the anode is unevenly consumed.

Risk Ranking
The objective of the risk ranking following the data collection is to establish priorities for the detailed examination in Step 3. For this, the threats and consequences as were defined in Step 1 are evaluated as risk, which is the product of the Probability of Failure (PoF) and the Consequence of Failure (CoF). The Risk Assessment Matrix as defined before (see Figure 2) is a grid which identifies levels of threat likelihood on the one axis, and levels of consequence severity on the other.

Step 3 – Detailed Examination
Based on the risk ranking conducted in Step 2, detailed inspections starting with the highest risk areas are conducted. Detailed visual inspection and appropriate NDE techniques are used to inspect coating damage/deterioration and corrosion, and to determine wall loss due to corrosion. The results of these inspections will be used to determine which areas require immediate action in order to lower the risk.

Detailed examination may entail specific tank access and quantitative monitoring in order to establish the coating condition and extent of the corrosion. For clarity it is emphasized that the subsequent inspection requirements are based on a company's risk acceptance and not related to statutory or class regulations. This evaluation may include consideration of excessive wall thickness loss (both general uniform and localized corrosion), the onset and growth of cracking, the magnitude of any stresses and loads, the performance and integrity of protective coatings, the level and effectiveness of corrosion mitigation schemes (e.g., cathodic protection and corrosion inhibitors), and environmental factors such as temperature, relative humidity, pH, and chloride concentration.

Detailed Examination for Different Zones

Submerged
Once the inspection locations have been identified by the Risk Ranking (Step 2), a close visual inspection (CVI) of the underwater locations is performed by diver or camera mounted ROV. Generally it is necessary to remove any marine growth in the region to be inspected. If indicated by the photography or video, ultrasonic thickness measurements (UTM) are also taken.

The underwater inspection should include a survey of the CP system, including measurement of the electrochemical potential at critical locations and visual/photographic assessment of the physical condition of the anodes (sacrificial and impressed current) and anode wires of the ICCP systems.

Splash Zone
After identifying the high risk locations in the splash zone, these locations are inspected in more detail using boats, divers, ROVs or rope access (usually with a change in trim or draft). In order to be able to carry out a detailed visual inspection, marine growth and corrosion product must be removed. Standard gauging and/or NDT (i.e. ultrasonic testing) are typically used for determining wall loss. Magnetic Particle Inspection (MPI) and/or Eddy Current Inspection (ECI) are commonly used to detect cracks or crack like features in special areas.

Top Side
An initial detailed visual examination may be sufficient to assess the threat, but also could identify the need for NDT, such as ultrasonic thickness testing. It should be noted that the most severe topside corrosion often occurs in crevices (i.e. narrow cracks), where localized crevice corrosion can result in rapid wall loss, under insulation and at the underside of a structure where salt, condensation and other deposits may build up and are not washed away by rain. Often, those areas of potentially severe corrosion are not easily detected.

Tanks and Internal Structures
Tanks and other internal structures require special attention, because of the presence of aggressive environments and because of poor accessibility; the steel walls are difficult to protect, because of the changing liquid levels. While the submersed areas are protected by a combination of coating and cathodic protection (sacrificial anodes) and the upper areas by a coating, the areas at highest risk are those subject to alternate immersion and drying.

Thus, tanks and internal structures are visually examined in detail, where accessible with particular focus on the wet-dry zones. These areas are inspected with close visual inspection and where required with appropriate NDT tools.

The submerged areas are initially inspected by assessing the effectiveness of the sacrificial anode protection system, which can be accomplished by measuring the electrochemical potentials at the location identified as "hot spots". If these measurements indicate insufficient cathodic protection, the anodes must be checked and where needed replaced. If after replacing the anodes, the level of protection is still insufficient, diver may be needed for further inspection.

Step 4 – Remediation and Repair

The detailed examination in Step 3, not only resulted in more detailed information on coating damage and corrosion, it also revealed those areas which require follow up step in the form of remediation. Depending on the degree of corrosion damage, the rig owner can decide on replacement, repair and/or improved corrosion management (incl. mitigation). If replacement or repair is selected, the resulting structure must be protected from future corrosion by proper corrosion management. The objective of remediation is to lower the probability of failure, i.e. to lower the risk to the structure due to corrosion.

The evaluation and selection of protective measures against corrosion depend on the operational philosophy of the rig owner, the market, type and age of unit, trade, costs relative to the unit's lifetime, etc. There may also be new regulations affecting allowable methods. The most important means of corrosion protection are:

- Coatings
- Cathodic Protection
- Corrosion Monitoring
- Corrosion Inhibition.

Step 5 – Life Cycle Management

In order to continuously maintain or improve the effectiveness of each of the 4 steps discussed above, a life cycle management process must be implemented. The life cycle management step is a continuous circle, which uses all 4 steps to create confidence in the condition of the rig and the process that is in place for corrosion management. This step is used to determine life expectations of the rig and adjust the rig strategy accordingly. The major objective of this final step is to increase the performance and reliability of the rig.

Offshore installations are designed to ensure a safe and economical operation during their intended life. Deterioration processes, such as corrosion and fatigue crack growth commence from day one. Thus, in order to ensure that the condition of the installations remains in compliance with the safety requirements throughout their operational life a certain amount of inspections, condition monitoring and maintenance is required throughout the service life of the installations. The control and steering of these inspections, monitoring and maintenance is part of life cycle management, with the objective to:

- Create confidence in the condition of the offshore rig and the process in place for corrosion management.
- Enhance the performance of the rig by establishing a cost-effective maintenance and inspection plan. Increase the reliability of the rig through consistent inspection planning and reporting.

Taking the 4 steps in a continuous cycle, results in the risk-based corrosion management process becoming part of the life cycle management, and as such contributing to the above stated objectives. The continuous cycle is formed by communication and review of each step as illustrated in Figure 4.

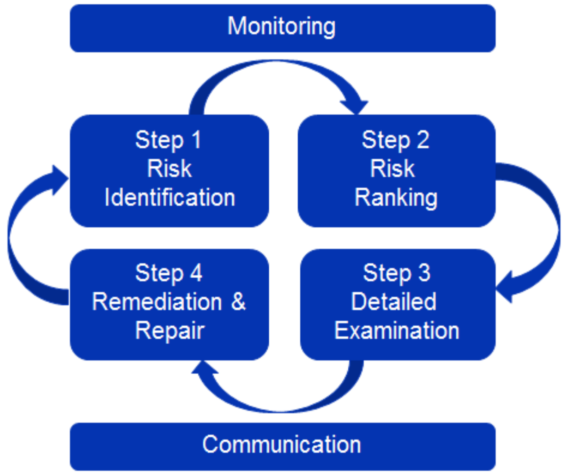

Figure 4 - Step 5 - Lifecycle Management based on the ISO-31000

The above makes clear that the monitoring and review process is not only part of the risk management process, but also part of the life cycle management process. Table 2, below lists each role from both the risk and life cycle management perspectives.

Risk Management	Life Cycle Management
• Ensure all controls are effective • Provide guidance on actions taken • Obtain further information to improve risk management • Analyze lessons learned • Detect changes to risk criteria that can lead to revision of risk ranking and risk treatment	• Buildup detailed picture on asset condition augmented with risk assessments • Create asset confidence • Reassessment of asset strategy • Reassessment of inspection maintenance strategy

Table 2 – Relationship between Risk Management and Life Cycle Management

It is emphasized that the re-assessment of asset strategy, inspection and maintenance strategy as listed in the right column, is based on an established risk picture. As such, the life cycle management becomes risk based as well.

In addition, it is highlighted that the above stated re-assessment does not only focus on reducing the higher risk areas. It may well be that inspection and maintenance intervals are acceptable in the low risk areas and as such cost over the life cycle is lowered.

Conclusions

This paper describes a risk-based approach to corrosion management for offshore structures. The objective of this approach is to reduce the risk of corrosion related failures and resulting downtime of offshore rigs, while at the same time improving the cost-effectiveness of corrosion inspection and treatment.

Corrosion is particularly detrimental to the integrity of offshore structures and if not managed properly will increase maintenance costs, the risk of downtime, or, shorten the life of the unit. Consequently, there is a need to manage corrosion, so the ongoing integrity and safety of an asset can be assured.

The proposed solution is to adopt risk based corrosion methodology described in this paper, which will provide confidence to the operators and demonstrable evidence to key stakeholders that corrosion is being managed on their assets. It will account for life extension, reduce the risk of corrosion failure, and lower the cost of inspection and maintenance.

The risk-based corrosion management process for offshore structures described in this paper consists of five (5) basic steps: Pre Assessment; Screening and Risk Ranking; Detailed Examination; Remediation and Repair; and Life Cycle Management. The presented methodology is based on the principles of ISO 31000 (Risk Management - Principles and Guidelines) to provide a solid consistent framework for corrosion management.

Nomenclature

This section lists the acronyms used in the paper:

ALARP	As Low As Reasonably Possible
CoF	Consequence of Failure
CP	Cathodic Protection
CVI	Close Visual Inspection
ECI	Eddy Current Inspection
FEA	Finite Element Analysis
FPSO	Floating Production Storage and Offloading
GVI	General Visual Inspection
ICCP	Induced Current Cathodic Protection
IMO	International Maritime Organization
ICCP	Impressed Current Cathodic Protection
ISO	International Organization for Standardization
MIC	Microbially Influenced Corrosion
MOU	Mobile Offshore Units
MPI	Magnetic Particle Inspection
NACE	National Association of Corrosion Engineers
NDT	Non-Destructive Testing
NPV	Net Present Value
OS	Offshore Standard
OSS	Offshore Service Specification
OTC	Offshore Technical Guide
PoD	Probability of Damage
PoF	Probability of Failure
RAM	Risk Assessment Matrix
ROV	Remote Operating Vehicle
RP	Recommended Practice
SRBs	Sulfate Reducing Bacteria
TTF	Time to Failure
TTFF	Time to First Failure
UTM	Ultrasonic Thickness Measurement

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