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Life Extension of Ageing FPSO and SPM Calm Buoy Hulls and Deck Plates Under Corrosion Effects - Part 1A

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Abstract: *This study entails the understanding of surveillance data that determines mitigation strategies on ageing and structural health challenges on hull and deck plates which drives life extension decisions on floating assets. The reviews focussed on structural health issue such as corrosion wastage on floating facilities hull and deck plates. Thus, data gathering, their interpretations and managements were found useful towards life extension project delivery. It was observed that the number of new floating production storage and offloading (FPSO) and single point mooring calm buoy (SPM) built for support of various oilfield production and export operations will continue to increase while the existing ones is near the end or have exceeded the end of their design operational life. The study shows that floating facilities undergo four stages of degradation viz: initial, maturity, ageing and terminal stages. The menace of corrosion wastages was observed in this study as one of the long standing challenges encountered by FPSO and SPM calm buoy hulls and deck plates. It was observed that previous studies relied on data gathered from trading/shuttle tankers to carry out this study on FPSOs, while others rely on data obtained from laboratory in corrosion coupon. While FPSOs are stationed in an oilfield and hardly relocates during their service life, trading tankers moves from one region of the ocean to the other, thus exposing them to various sea state and varying corrosion conditions. On the other hand, data obtained from corrosion coupon in laboratory is under control while that obtained from an FPSO operational location is in real marine environment and represents the real state of corrosion wastages. Thus, corrosion data obtained from an FPSO/SPM calm buoy operational location in marine environment represents a more realistic data in marine corrosion wastage case studies. Therefore, it was observed that more case studies should be carried out on different floating assets in the areas of corrosion wastages. More so, the validity of data used for life extension studies were observed as 18 months by some class society, while some oil majors allow data taken within 5 years before the end of life, but such data must be subjected to review by a subject matter expert. Similarly, minimum of 5 gauging points per area of* $1m^2$ *deck plate strake or zone is required unless where there is marginal corrosion wastage that would require 8 gauging points.*

Keywords: FPSO, SPM calm buoy, hull, deck plates, end of design life, corrosion wastages, mitigation strategies, life extension, certificate of class.

INTRODUCTION

For those involved in upstream oil and gas exploration and exploitation, floating production, storage, and offloading (FPSO) is a new technology with a bright future. The data that is now available worldwide indicates that both the demand for FPSOs and the expectations for oilfields with high productivity have increased. FPSO and SPM calm buoy are usually designed to serve for 20 to 30 years according to owner and class society discretions. However, towards the end of their design operational life, an operator is usually required to make a business decision for continued or further use in what is called life extension. These changes have made it necessary to prolong the service life of current FPSOs [1]. However, hulls older than 30 years are present in about 45 percent of all FPSOs. Life extension projects discussions is gradually dominating offshore Brazil and West Africa often called Gulf of Guinea (GoG). When an oilfield reaches the end of its originally planned service life, FPSOs offer a feasible alternative for life extension, whether at the same oilfield location or migration to a new oilfield. While some FPSOs are being converted from existing shuttle or trade tankers, the majority have been on operational duty for a long time. It is crucial to remember that, in light of safety, structural integrity, and financial considerations, a trustworthy process for evaluating FPSO structures with designated scantling is required in order to confirm structural integrity following FPSO life extension and relocation [2]. The availability and accessibility times for different tank inspections during their operations and maintenance, as mandated by both in-house operator integrity programs and class society integrity surveillance programs, are among the primary issues with FPSO integrity management. In order to define the scope of inspection and enable more accurate mitigation measures to be implemented in order to lessen or prevent an increase in future surveys, operators and researchers working on life extension studies should concentrate on a thorough methodology for corrosion wastages and rates [3]. Operators frequently have to make a solid commercial decision to prolong the operational life of FPSOs when they approach the end of their design life. There are technological and economic components to this firm's wise business choice. either to keep producing from an already-existing, productive oilfield or to take advantage of or investigate additional satellite oilfield options that may be able to be tied back to the current host FPSO. As is frequently the case with leased FPSOs, the technical aspect aims to postpone new CAPEX in the purchase of new floaters [4]. Once the existing FPSO has been verified to be structurally adequate for the anticipated years of life extension, FPSO owners and operators choose to implement a life extension program on ageing FPSO rather than constructing a new one in the competitive, low-profit business environment of today.

From the standpoint of cost and risk management, the technological side of life extension offers special opportunities and challenges for reverse engineering. In order to ascertain whether an existing FPSO is suitable in terms of safety and integrity for the planned period of life extension, it is necessary to conduct a thorough structural re-assessment of the FPSO from its current, as-in condition, with any mitigation or repairs made to achieve the ultimate goal of defined additional life of extension. It was stated in [5] that the Bonga FPSO was put in place in 2004 with a 20-year design life. In order to produce hydrocarbon tail volumes from the field in addition to infill volumes from satellite developments, such as the Bonga North tie-back project, the Bonga main life extension project recently extended the FPSO's life for an additional 15 years. The authors concluded that an insitu (on site) life extension rather than dry docking was adopted. One of the most difficult problems FPSO has encountered during their design service life is the catastrophic threat of marine corrosion wastage. The main parts of the FPSO that are susceptible to corrosion wastage are the deck plates and hull. As the FPSO matures, the phenomenon of corrosion wastage grows increasingly serious and difficult. The most significant causes of age-related structural deterioration and FPSO hull and deck plate deterioration are thought to be corrosion and corrosion-induced problems. From the perspective of integrity and safety, corrosion can result in penetration and thickness reductions, which are harmful outcomes. It is well recognized that the effects of marine corrosion wastage might compromise the hull and deck plates' structural integrity. Some classification societies, like ABS, advise local plate thickness reductions of roughly 20 to 25 percent from strength considerations because marine corrosion wastage threshold values cause FPSO hull and deck plate strakes mitigations like protective coating replacement, plate repairs, and plate replacements. A plate's remaining thickness is a measure of its residual strength because plates are evaluated according to their original thickness and ultimate tensile strength. A plate's strength decreases as its thickness decreases.

The FPSO deck plate strake architecture is designed to have a thicker plate strake where increased deck loading is anticipated. The majority of this field's study was conducted using data from trade tankers, which FPSO is required to use for research and information exchange. Others were conducted using data collected in a controlled laboratory corrosion coupon. More corrosion wastage case studies are needed, according to [6] and [7], who suggested that future studies should look at using monitored data from a floater operating in an uncontrolled marine corrosion environment rather than data from trading tankers or corrosion coupons collected in a lab. This is due to the fact that corrosion wastage studies are more realistic when they use data from actual corrosion environments. In order to determine its structural sufficiency for the projected 15-year life extension, the current study used historical data from an FPSO in the GoG. To make decisions about life extension, the historical data was gathered, compiled, and examined. The first step is to ascertain whether the FPSO hull's remaining thickness is suitable for an extra 15 years of life extension. Second, to assess the deck plates' state and offer suggestions for maintenance, replacement, and renewal. The hull and deck plates in different strakes only experienced varying degrees of general/pitting corrosion wastage, despite a survey report conducted on them prior to this investigation indicating that there were neither cracks nor dents. Equations based on class society rules were used to assess the FPSO hull's suitability for the anticipated number of years of extension, and mitigating measures were implemented for the deck plates' pitted or severely corroded strakes and zones. It's interesting to note that the majority of the scholarly publications that are now available only discuss particular facets of the difficulties. However, the majority of classification organizations just gave the owners of FPSOs awkward and pointless guideline notes as a framework for life extension. This study offers a thorough approach to the as-gauged scantling method, which is typically used by FPSO owners and operators to assess the hull's fitness for a 15-year life extension under the effects of corrosive wastage.

Interestingly, [8] suggested that the anticipated life extension for the refurbished and upgraded floating facilities should be more than 16 years in order for them to be more cost-effective and lucrative in the long run. Notably, econometrics and asset economics are essential to life extension planning, maintenance, repairs, and inspections. Similarly, it was estimated that the procurement of a new-built FPSO and SPM calm buoy would cost USD 12 billion, while the life extension of the Bonga FPSO and SPM calm buoy would cost USD 2 billion. The operators' preference for floating facilities for life extension is justified by the cost disparities. It was state that the Bonga FPSO was put into service in 2004 after a 20-year design life [5]. According to the authors, the Bonga main life extension project was successful in extending the FPSO's life for a further 15 years, allowing it to produce hydrocarbon tail volumes from the field in addition to infill volumes from subsequent expansions, such as the Bonga North tie-back project. Instead of using dry docking, the authors decided to use an insitu (on site) life extension. In order to determine the extent of plate strakes that need to be repaired, renewed, or replaced, corrosion wastage data on the main deck plates is analyzed using equations based on class society rules. Protective paint coating, additive patches, crop and weld, weld infill, and sandwich plate systems are a few repair techniques. The significance of the suggested methodology is justified by the fact that the data and research articles that are now available in both the academic and industry domains do not provide a thorough assessment of that possibility. With the help of a computer software, this research suggests guidelines for managing the life extension process for FPSO hull and deck plates. In order to help the decision-making process for extending the life of hull and deck plates and to make it easier to analyze issues associated with ageing, a framework including the primary evaluation steps has been strengthened. While ageing has been found to have a considerable impact on hull damages, structural damage has been highlighted in multiple investigations as a major contributing cause to marine incidents. Thus, the aim of this research paper is to address issues on life extension of ageing FPSO and SPM calm buoy hulls and deck plates under corrosion effects. To adequately carry out life extension, the interests of stakeholders such as class society, regulators, insurer and owners must be carefully evaluated and protected. Part of the business decision requires asset portfolios valuations to ascertain the oil and gas reserves remaining in the location. The other is the technical aspect which requires a careful evaluation to ascertain if the FPSO and SPM calm buoy hulls and deck plates is fit for purpose or requires some hull and deck plates mitigation strategies such as repairs, upgrade to serve for the additional years of life extension. Usually, these repairs decisions are historic data driven. The primary NDT data are collected, collated, analysed and interpreted to make hull and deck plates strakes or zones plates repairs or renewal decisions. They are done according to class society requirements and supervisions.

Ageing and Age-Related Structural Degradation and Deterioration

FPSO and SPM calm buoy ageing refers to the gradual degradation and deterioration of the hull structures that occurs due to typical operational use and environmental causes. Nonetheless, the different ways that their structure deteriorates take the following forms:
(a) Damage to protective coatings
(b) Wastages from corrosion
(c) Cracking;
(d) Dents or other deformations; and
(e) Modifications to the material's characteristics.

Protective Coating Damage

Through-film breakdown, delamination, cracking, too-thin coating, edge breakdown, blistering, weld corrosion, rust, calcareous deposits induced coating failure, reverse impact damage, stress-related coating failure, and flaking are some of the patterns of protective coating deterioration. However, when structural deformation outweighs paint film lengthening, protective coating cracking happens [19]. Blisters, on the other hand, develop if the protective paint coating's grip is locally compromised. Interestingly, blisters are known to contain liquid, even if the blister's underside is corrosion-free. Additionally, flaking describes the paint layer lifting from the underlying surface. Inadequate surface preparation, incompatibility with the under layer, and interlayer contamination result in the loss of protective covering paint bonding. SA 2.5 or SA 3.0 are the ideal surface preparations for protective paint coating applications [37]. That is both thorough and extremely thorough blast cleaning. Likewise, the elements influencing the performance of protective paint coatings are categorized as follows:

(a) Environmental factors
(b) Operational factors
(c) Coating related factors
(d) Design and fabrication factors
(e) Maintenance and inspection factors.

High humidity, high concentrations of salt, weathering, temperature, and ultraviolet radiation are all components of environmental variables. Conversely, coating-related criteria include paint kind and quality, surface preparation, drying and curing, paint thickness and uniformity, and application technique. In a similar vein, the operational considerations include foot traffic, chemical exposure, mechanical stress, cleaning, and maintenance [12]. FPSOs typically have a lot of foot traffic in the laydown/landing base regions on the main deck. Furthermore, deck plan and design, material selection, fabrication, and welding are often the design and fabrication elements. Last but not least, the maintenance and inspection aspects examine touch-ups, repairs, maintenance scheduling, and routine surveys [9],[10],[11],[. There are numerous causes that lead to corrosion and coating deterioration. The following are some of the contributing factors: cargo type and acidity, ballasting frequency and method, trapped water or oil, oxygen and sulphur concentrations, salinity of ballast water, temperature, humidity, pollution, trade route, structural flexibility, corrosion protection effectiveness, marine fouling, corrosion films, flow rate, stray-current, cargo residues and mechanical abrasion, maintenance and repair, construction material, microbial attack, sludge/scale accumulation, etc. 12],[13],[14]. These elements can function alone or in concert, and it is challenging to measure their effects. Therefore, the placement of the member determines how much corrosion wastage in structural members [15], [16],[17],[18],[19].

Corrosion Wastage

The slow deterioration of a metal brought on by an electrochemical or chemical reaction with the environment, such as seawater, is known as corrosion. According to [20], there are several common types of corrosion, including uniform or general corrosion, pitting corrosion, stress corrosion cracking, corrosion-induced fatigue, and microbiological-induced corrosion. The most prevalent type of corrosion wastage is general or uniform corrosion, which causes deterioration and deterioration to spread evenly across the hull and deck plate surface [17], [18].

Pitting Corrosion

A common localised corrosion pattern on the underside of ballast tanks and in certain places on main deck plates is pitting corrosion. The surrounding environment determines the pits' shape [21]. In their research, [22] found that pitting corrosion using semipermeable membrane materials can result in a pit with an open (uncovered) or covered mouth. However, as noted by [7], pits can also be hemispherical or cup-shaped, with flat walls that display metallic crystal structure, or they can be completely irregular in shape [6]. Interestingly, [23] noted that the voids of pitting may be filled with corroded products that form caps over it and occasionally form nodules or tubercles. Nevertheless, pit shapes are often categorised into trough pits (upper) and sideway pits (lower). The most severely pitted cross section of any structural part is thought to span the plate breadth in the current dependability assessment [24]. This is useful for the reliability assessment, but it can give a quite negative assessment of residual strength [7]. Although this is not taken into consideration in the current illustrated calculations, the author claimed that in practice, pits will be mended after they reach specific depths and extents, independent of the associated strength criterion.

This is because pitting is small, it is a harmful localised corrosion that is difficult to detect. Even though a pit may appear small on the deck plate's surface, it may appear larger beneath the undercut surface, where it is covered with rust or film [17]. Despite their perforation, deck plates deteriorate due to pitting corrosion with minimal weight loss. Pits vary widely in depth and spread under comparable conditions, making measuring difficult. Interestingly, pits can take months or even years to incubate [16]. The overall amount of time needed for a deck plate strake or zone to undergo crack nucleation up until the point at which the crack intensifies to the point where it may ultimately result in strake or zone failure is known as the pits incubation period. Cracks may start, spread, and expand in induced corrosion pits, which are concentrated areas of stress. However, the type of material, the stress state, and, finally, the local solution conditions are the primary factors that determine the pitting intensity or the rate of pit growth once it begins. The use of inorganic-based inhibitors improves the reduction of corrosion wastage from pitting deck plates in aggressive media like saltwater [18]. The different pitting profiles are depicted in Figure 1. On the other hand, figure (2) shows the assumed corrosion reduction progress

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for a few chosen elements of the object FPSO structure. Environmental parameters like PH, inhibitor concentration, aggressive ion concentration, surface condition, temperature, pitting potential, and metallic composition are the elements that cause pitting corrosion [19]. Reductions in thickness, loading bearing capacity, fatigue strength factor of safety, remaining strength, geometric faults, and cracks are some of the significant effects of corrosion wastage on deck plate strakes. However, if prompt repair measures are not implemented, thickness losses above a threshold value may result in cracking. Conversely, floater size, form, operating conditions, loading conditions, and material choice all affect how thick deck plates are. Other design and regulatory requirements focus on structural integrity, corrosion prevention, and class society regulations.

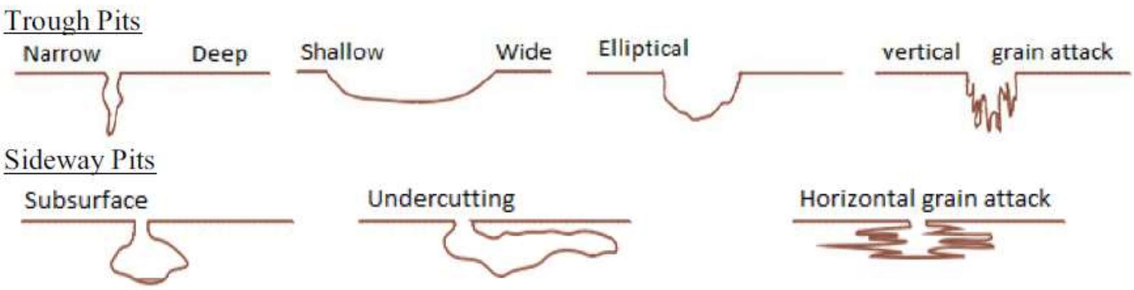

Figure (1): Various pitting profiles [22].

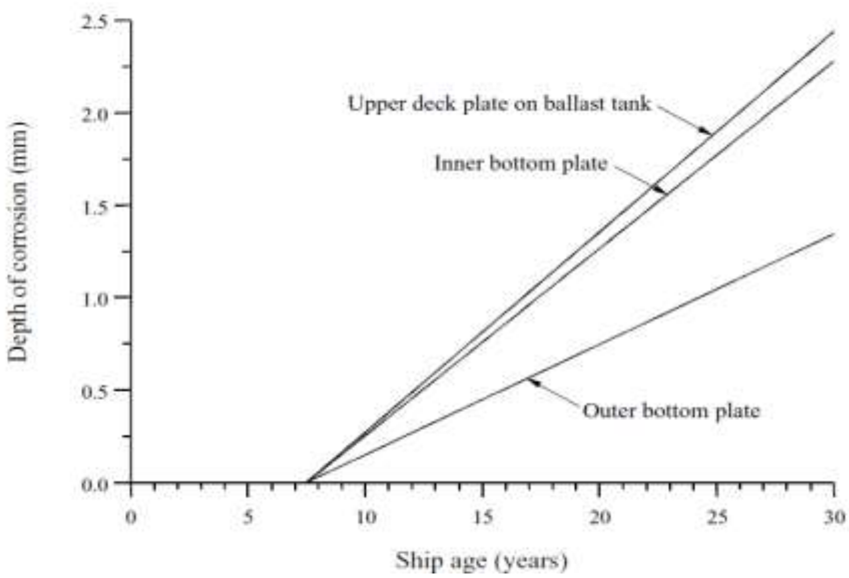

Figure (2): Presumed progress of corrosion diminution for selected members in the object FPSO structure [7].

Microbial Induced Corrosion

This is because of their corrosive wastage products; microorganisms can also produce localised corrosion on the strakes of ballast tank plates. This phenomenon is known as microbial induced corrosion. Sulfur-reducing bacteria (SRB) and acid-producing bacteria (APB) are the most prevalent types of bacteria [15]. Under anaerobic conditions, SRB causes corrosion. Through ballasting activities, the SRB enters the ballast tanks together with the sediments and debris they consume. Anaerobic bacteria, as they are affectionately known, are bacteria that live, grow, thrive, and proliferate in the absence of little to no oxygen [17]. When a metal is mechanically stressed when exposed to a corrosive environment, certain alloy and environmental combinations can cause stress corrosion cracking. Rust is a by-product of metal surface corrosion caused by hydroxides and oxides. The paint coat is destroyed and the range of rusting increases since the early rust is hygroscopic and porous [20]. Where there is insufficient paint film adhesion and a paint film break, rust is produced.

Cracking

Cracks frequently result from weld defects. Crack initiation may also result from an impact from a falling object or an unintentional overload [6]. Such early breaking might develop into a crack that keeps spreading under repeated stresses and so enters the ageing regime if it is not noticed and fixed right away.

Life Extension Procedures and Process

The main question in this study is essentially whether to decommission the floaters or keep using them for life extension. The engineering solution hinges on whether a business-economic case can be made for the oil and gas reserves in the oilfield and, thus, for the FPSO/SPM calm buoy life extension, and whether a combination of structural upgrades/modifications and mitigating actions will be adequate to demonstrate compliance with national and international safety requirements, such as those of a classification society covering such assets. Table 1: Oil majors' oil reserves in Nigeria's deep offshore. Table 2: Nigeria's list of recently constructed FPSOs. A life extension evaluation flow chart is shown in figure (3) in order to actualise these things. The technical drivers are mainly determined by the availability of data for evaluation and decision making such:

(a) Operators and class surveys: Technical assessments like fitness for service are made using the findings of surveys that are conducted jointly or independently [16]. While the class society hires an impartial third party whose staff must have been approved by them to conduct such an inspection campaign, the floaters owner maintains an internal inspection team. Notably, the third party's findings-particularly on the gauging of hull and deck plates-are adopted by the class and have a significant impact on life extension [18]. This is due to the fact that the class society will provide the certificate of life extension, which will attest to the facility's compliance and fulfilment of the minimal requirements for life extension. The class society is still in charge of issuing certificates of class and conducting renewal surveys every five years [14]. When the class and extension certificates are shown, insurance firms use their professional judgement to insure the floater.
(b) Technical decisions are enforced using historical data from repairs and maintenance.
(c) Studies on the viability of repairs, upgrades, and modifications, as well as corrosion wastage management, assist the operator in making quick technical business decisions [19].
(d) Corrosion protection system: To assess the extent of repairs needed to support a life extension project on floaters, the ICCP, sacrificial anodes, painting, and coatings are often assessed.
(e) Hull integrity: The crucial component is examined to determine whether it is suitable for its intended use or whether necessary repairs are suggested for close out.

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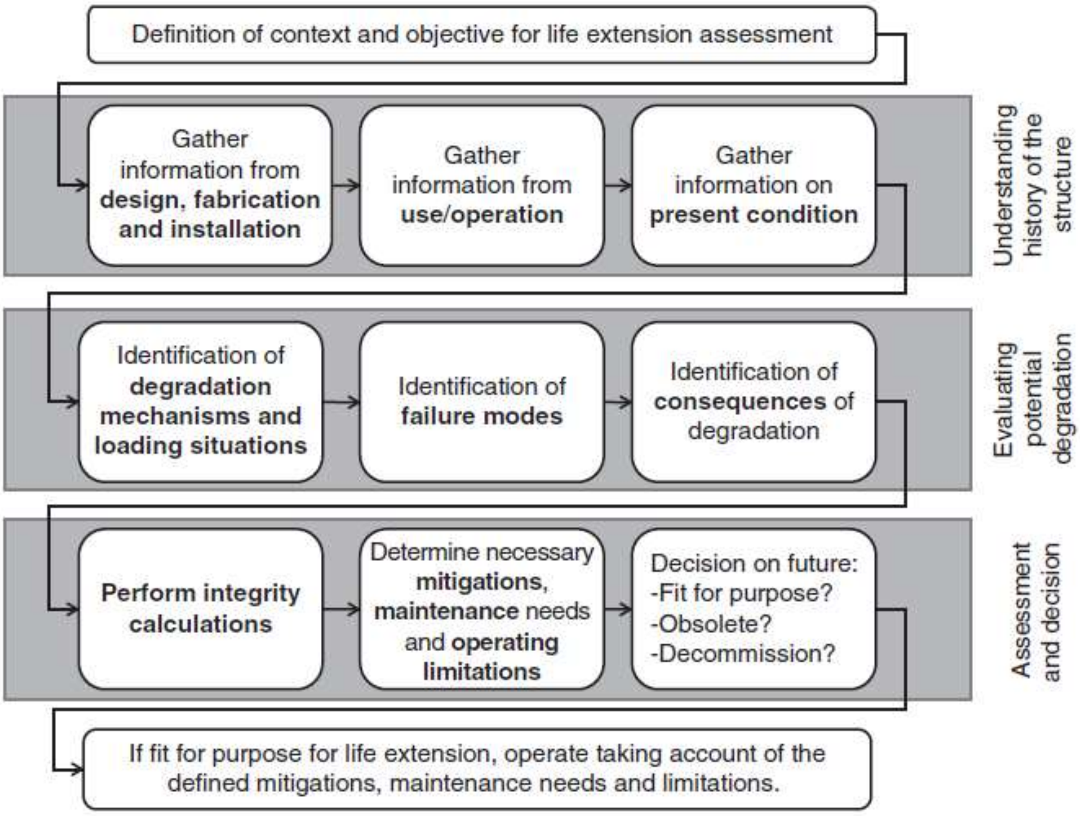

Figure (3): A flow chart for life extension assessment [25].

Table (1): Oil reserves in deep offshore Nigeria by oil majors [26]

Oil Field	Water Depth (m)	Operator	Reserve
Usan	850	Esso	Recoverable reserve: 68 x 10^6 tons.
Erha	1200	Esso	Recoverable reserve: 68 x 10^6 tons.
Bonga	1000	Snepco	Recoverable reserve: 82 x 10^6 tons.
Agbami	1463	Chevron	Estimated total reserves: 136 x 10^6 tons.
Akpo	1400	TotalEnergies	Proven and potential reserve: 85 x 10^6 tons. of condensate oil and 28.3 x 10^9 m^3 natural gas
Egina	1600	TotalEnergies	Probable reserve: 75 x 10^6 tons.

Table (2): List of new built FPSO in Nigeria [27]

Operator/Owner	Facility Name	Water Depth (m)	Design Life	Year on Location	Expected End of Life
Esso	Usan FPSO	850	20	2012	2032
Esso	Erha FPSO	1200	20	2006	2026
Snepco	Bonga FPSO	1000	20	2004	2024
Chevron	Agbami FPSO	1450	20	2008	2028
TotalEnergies	Akpo FPSO	1400	20	2009	2029
TotalEnergies	Egina FPSO	1600	20	2018	2038

According to [28], floaters are placed in areas with a particular design life that is typically in line with the field life. Although there are floaters placed with design lives longer or less than 20 years, a typical design life is 20 years. Remarkably, the majority of them are built to run continuously on-site without the need for dry docking. The owner or operator of a floater may want it to stay in place and carry on with production operations as it nears the end of its design service life. According to [29], the owner or operator usually starts the life extension process with the local regulatory body or a classification society. To extend the life to the new working life decided upon by the owner or operator and the classification society, an assessment is conducted and the necessary steps are implemented. A re-evaluation of the floaters system, including the hull and deck plates, is part of this procedure. Usually, both engineering and surveying are part in this re-evaluation. The following components are part of the life extension techniques for FPSO and SPM hulls and deck plates: We have the following for hull deck plates:

(a) Cathodic protection
(b) Painting and Coating
(c) Frequent plate thickness measurements or gauging (UTM)
(d) Fitness for service examination and evaluation
(e) Repairs and replacements

Inspections/Surveys and Data Gathering Methodologies

However, the main purpose of ultrasonic thickness measurement (UTM) in floating structures is to measure thickness, and it is especially useful for keeping an eye on component corrosion [6]. Therefore, the goal of this mode is to measure the amount of time needed to receive a signal that has been reflected off the rear wall [7]. Generally speaking, deck plates should have five gauging points per one-square-meter strake. However, in cases where significant corrosion wastage is evident, eight points of gauging should be performed, followed by thorough visual inspections. The class surveyor in attendance will then pay close attention to these strakes or zones, and they will be marked for close monitoring in subsequent surveys. The UTM setup is shown in Figure (4).

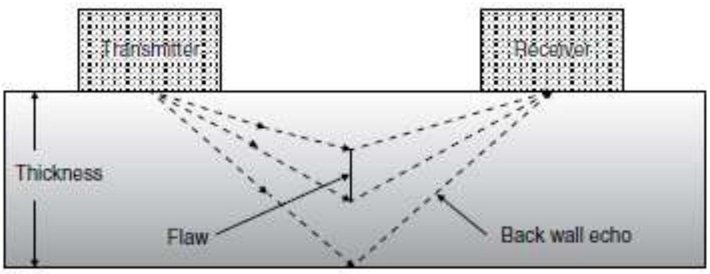

Figure (4): UTM set up [30]

Machinery, station keeping, and hull girders, including the main deck plate, ballast tanks, transverse and longitudinal girders, vertical and horizontal girders, frames, stiffeners, web frames, stringers, etc., are essential parts of a floating manufacturing establishment. When evaluating the corrosion wastage of FPSO/SPM calm buoy hull deck plates, its interesting to note that the main choice is which parameter needs to be identified and measured:

(a) Average remaining thickness,
(b) Minimum thickness, and
(c) Maximum pit depth or pit intensity (as a percentage of the plate surface).

However, [7] concluded that in current corrosion wastage monitoring practices;

(a) Average remaining thickness and
(b) Maximum pit depth; are considered to be primary parameters of corrosion in terms of repair criteria, but the trend is now towards a more quantitative definition of:
(c) corrosion intensity.

Inspection/Surveys Planning Philosophy

The development of planning philosophies for inspection of structural condition is shown in figure (5). A good inspection campaign is dependent on time, cost and technology involved.

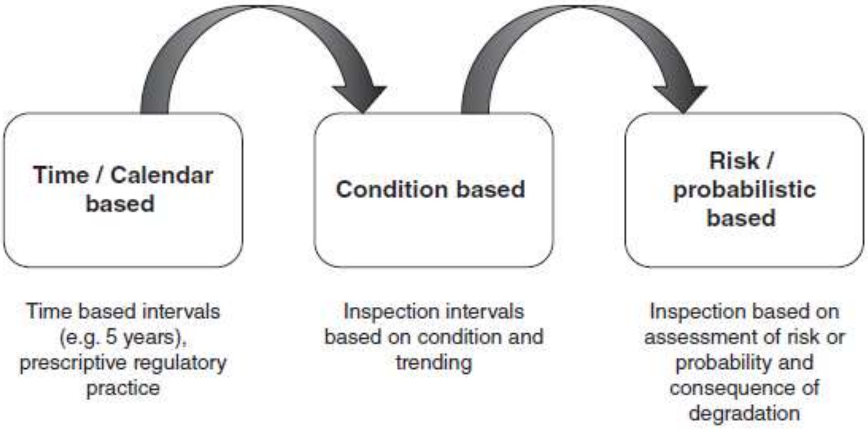

Plate (5): Development of planning philosophies for inspection of structural condition [25]

Floating systems are easier to survey, but they lack the inherent redundancy of fixed installations [25]. Some underwater surveys can be conducted in the dry dock, either by de-ballasting or dry-docking [29]. For this reason, it is necessary to shut down the floating facility [31]. According to [6], a lot of floating facility operators presently focus their surveys on the parts that are most likely to exhibit early deterioration, failure, damage, or degradation based on structural assessments or historical data. The engineering materials used to build floating facilities are produced at several industries. It's interesting to note that steel has the most applications of any technical material. Notably, engineering materials undergo modifications from the moment of fabrication to the point of installation [7]; these changes must be controlled to maintain the adequate safety of both fixed and floating facilities [30]. Some of these modifications have a direct impact on the safety of the floating facilities [25]. Fatigue, corrosion, material deterioration, variations in the weight and loads placed on the facilities, and the way the facilities are used are a few examples of this [6]. However, floating structures must be designed, built, and installed for safe operation throughout their design life as part of engineering practice [31]. However, cyclic loads, the nature of the operating environment, and unplanned events will result in anomalies that, if not identified, controlled, and fixed, could lead to the failure of the impacted floating facility component [32]. However, the likelihood of these anomalies happening rises with age [33]. The identification and prevention of material failures in a variety of industries, particularly the offshore sector, has been transformed by non-destructive testing, or NDT, techniques [34]. Defects typically arise during the building and operation phases [7]. Depending on the material, temperature, stress level, and loading rate (frequency), metal can fracture in a variety of ways [6].

Remarkably, the failure of engineered materials results in fatalities, financial losses, and disruptions to the supply of goods and services [30]. According to [35], poor component design, poor processing, and inappropriate material selection are all blamed for engineering structural failure. Three stages of failure-crack initiation, growth, and propagation-are recognised. Notably, the goal of a floater's different technical examinations is to conduct a thorough assessment and track the state of various components, including the hull, mooring, machinery, safety systems, and equipment, to ensure that it is suitable for its intended use. A certified surveyor from a registered classification association often undertakes it. Examples of survey types are:

(a) Initial survey
(b) Annual survey
(c) Periodic survey
(d) Intermediate survey
(e) Renewal survey
(f) Special purpose survey

It was pointed out in [36] that before a floater is put into service or when a new instrument is applied to an existing floater and the necessary certificate is given for the first time, the first survey, as mandated by the applicable maritime legislation, shall be completed. To guarantee that the requirements pertinent to the specific certificate are met and that the structure, machinery, and equipment are suitable for the service for which the floater is intended, [15] and [37] noted that the initial survey should include a thorough inspection, with tests when necessary, of the structure, machinery, and equipment [38],[6]. However, a certificate of class will be awarded for the first time together with other certificates at the conclusion of the original survey, and it typically lasts for five years. The floater was planned and built in compliance with the classification society's rules and regulations, as attested by the certificate of class. To retain class, the classification society will continue to attend the floater for yearly and frequent surveys during the course of the five years. It is crucial to remember that the certificate of class is distinct from other certificates, including those for international oil pollution prevention, load line, safety construction, and safety equipment. One important point is that the certificate of class is crucial as the floater's insurer (insurance company) is requesting and seeing it. However, the following should be included in the first survey:

(a) A examination of the calculations, specifications, plans, diagrams, and other technical documents to confirm that the machinery, equipment, and structure meet the standards pertinent to the specific certificate [15].
(b) An examination of the machinery, equipment, and structural integrity to make sure that the construction, materials, scantlings, and arrangements, as applicable, match the authorised plans, diagrams, specifications, calculations, and other technical documentation; additionally, the workmanship and installation are deemed satisfactory in all aspects [39].
(c) Verification that all of the operating manuals, record books, certificates, and other documents and instructions included in the requirements pertinent to the specific certificate have been put on board the floater and are easily observable [40].

As demonstrated in [38], According to the applicable requirements, the yearly survey must be conducted three months before to or following each certificate anniversary date. An annual survey should allow the classification society to confirm that the floater's condition, along with that of its machinery and equipment, is being maintained in compliance with the applicable regulations [40], according to [37]. Nonetheless, the following should constitute the annual survey's scope:

(a) A certificate examination, a visual inspection of the floater and its equipment to a suitable degree, and specific tests to verify that their condition is being appropriately maintained should be included.

(a) A visual inspection should also be part of it to ensure that the floater and its equipment have not undergone any unauthorised modifications [40].

Notably, the applicable maritime regulations stipulate that a floater's periodic survey must take place either three months before to or following the second anniversary date [40]. It's interesting to note that the periodic survey should include an examination of the equipment, along with tests if needed, to make sure that the specifications pertinent to the specific certificate are met, that it is in good working order, and that it is suitable for the purpose for which the ship is built [38]. Checking that all of the certificates, operating manuals, record books, and other instructions and paperwork included in the requirements pertinent to the specific certificate are on board the floater should also be part of the periodic survey [36]. It was reaffirmed in [29] that the intermediate survey should replace one of the annual surveys and be conducted within three months of the appropriate certificate's second anniversary date or its third anniversary date, as required by the applicable maritime regulations. However, the intermediate survey should involve checking that the elements related to the specific certificate are in good condition and suitable for the service for which the floater is designed. The goal is to guarantee that the floater continues to operate safely and in accordance with all relevant laws and regulations. It is usually schedule every 2.5 years and aimed at verifying critical floater components.

Prior to the appropriate certificate being renewed, the renewal survey shall be conducted in accordance with the applicable maritime regulations [38]. With the intention of finishing by the fifth anniversary date, the floater renewal survey may be started at the fourth annual survey and may be advanced in the following year [36]. Additionally, the completion of the renewal survey should not be attributed to the survey items from the fourth annual survey [41]. However, the renewal survey should include an examination of the structure, machinery, and equipment, along with tests if needed, to make sure that the requirements specific to the certificate are met, that they are in good condition, and that they are suitable for the service for which the floater is designed [29], [42]. However, verifying that all of the certificates, operation manuals, record books, and other documents included in the requirements pertinent to the specific certificate are on board the floater should also be part of the renewal survey [40]. A class society certificate of class is issued as a result of this survey, which is typically carried out every five years and has the same scope as periodic surveys. Another name for the special purpose survey is the supplementary survey. Usually, it is carried out following repairs. To address some specific difficulties or concerns, like repairs, maintenance, and structural adjustments, a thorough structural examination is conducted. The replacement or repair of a deck plate zone or strake serves as an excellent illustration. The general process for maintaining or extending an aged floater's operational service life can be summed up as follows, citing [38]:

(a) A thorough examination of the existing state, engineering analysis, and baseline data.
(b) Examine and re-evaluate the hull construction.
(c) Identify areas that need to be repaired, modified, or subject to more thorough inspection and monitoring.
(d) Specify a way to modify the structure in areas that are prone to fatigue.
(e) Determine how long the hull deck plates will last.
(f) Request clearance for a life extension from the classification society [38].

Hull Data Measurements, Management and Interpretations

Choosing which of the following parameters should be detected and evaluated is the fundamental decision in the evaluation of corrosion wastage: average remaining thickness, minimum thickness, maximum pit depth, or pit intensity (as a percentage of the plate surface). Although the tendency is currently towards a more quantitative definition of corrosion intensity (corrosion wastage), the average remaining thickness and maximum pit depth are still regarded as the fundamental parameters of corrosion in terms of repair requirements [16], [17], [43], [6]. The class society rule stipulates that ultrasonic thickness measurement gauged data must have been obtained within the last five years in order to be used for hull and deck plate strakes or zones assessment as a baseline condition in a life extension project for FPSO and SPM calm buoys. Notably, consent from a subject matter expert should be sought before using data that is more than five years old. According to [44], the trend is currently towards a more quantitative definition of corrosion intensity (corrosion wastage rate), although the average remaining thickness and maximum pit depth are still regarded as the primary parameters of corrosion in terms of repair criteria. Regarding corrosion progression, wastage prediction, and corrosion rate over time, researchers do not appear to agree, according to [37]. Nonetheless, the researchers suggested that field data, not lab data, should serve as the foundation for a standard corrosion wastage model. Therefore, the data used and how these data are interpreted determine whether a corrosion wastage model is valid. Many corrosion papers have recently made available a large amount of data on marine corrosion wastage resulting from age-related problems [37], [45]. However, the thickness measurement data for the hull deck plates is helpful in determining the patterns of deterioration and corrosion degradation. Nonetheless, they were widely employed in the creation of analytical models for time-variant reliability analysis and corrosion wastage prediction [46], [44], [47]. In some cases, the validity of UTM data used for life extension decision making is placed at 18 months, beyond this period a new survey will be required to obtain new data for decision making. However, some IOCs in their procedures can use data obtained within 5 years of end of the design life but such data will be subjected to review by subject matter expect to determine if a new survey data will be required to make repairs decisions. A minimum of 5 gauging points per area of $1m^2$ deck plate strake or zone is required by class society unless where there is marginal corrosion wastage that would require 8 gauging points.

However, there is still a lack of interpretation on the trends found in different databases [48], [49], [50], [51]. However, [52] found that industry and academic projects like life extension case studies for floating assets like FPSO/SPM calm buoy hulls and deck plates also require the ongoing collecting and update of these information. Remarkably, uniform or general corrosion is the subject of the majority of the data that is now accessible [53], [54], [55]. However, there is still a dearth of information on other localised corrosion types, like pitting and grooving [56], [57], [58]. It's interesting to note that managing life extension campaigns requires effective data management for corrosion wastage and coating deterioration. Class and regulatory records and reports must be kept on board by operators of floating ship-shaped facilities utilised in oil and gas production operations, such as FPSO/SPM calm buoys [37], [59]. The majority of these reports or documents are regularly updated to take into account the most recent survey results and the classification status of floating facilities. This report, which is frequently called a class status report, lists every flaw discovered during surveys along with suggestions for fixing them. Documentation on board is a conventional shipping practice.

It was stated in [47] that FPSO must also maintain documentation on board; however, FPSO differs from ships in that they must maintain verification documents offshore. In order to maintain document changes, an onshore support team is established [37]. This can best be addressed by adopting data management technologies [37]. This guarantees that the processes and records kept on board are consistent with those that are accessible to support teams ashore [40]. The authors clarified that an effective centralised document management system can be used to accomplish this goal [47]. Such a system enables quick and simple onboard access to pertinent documents, according to [37]. Additionally, it offers a centralised framework for onshore base teams to share these documents [60]. The utilisation of satellite communication technology offers internet access from practically any area of the globe. According to the authors, this approach works well for offshore industrial operations. Major classification societies currently use web interfaces to offer services on data management and structural integrity for hull inspection, maintenance, and repair [61], [62]. The authors noted that using these methods enables different people to share documents. However, it also facilitates the tracking and retention of design and maintenance records by operational teams. Overuse of corroded strake/zone of deck plate can lead to fracture, buckling, or yield failure, according to [6], [7]. The hull deck plates become thinner as a result of corrosion wastage. The remaining strength, both local and global, is diminished by the erosion and corrosion of FPSO/SPM calm buoy hull structures, which might ultimately result in catastrophic casualties under extreme circumstances.

5.1. The Technical Implications and Economic Cost of Pitting Corrosion

Concern over the effects and ramifications of corrosion action is widespread. The threat of corrosion wastage often puts safety at risk, impedes the development of new technologies, and eventually results in missed production opportunities. The usable service life of floating equipment like FPSO and SPM calm buoy is shortened by corrosion degradation. When the proper corrosion margin is not maintained, the corrosion costs incurred by plate makers are also passed on to floating facility operators. The calm buoy hulls and deck plates of the FPSO and SPM are vulnerable to corrosion. The top plate, mid upper plate, mid lower plate, bottom plate, and floor plate comprise each of the compartments that the SPM calm buoy has built in for the seawater ballast tanks. Additionally, the FPSO ballast tanks are divided into sections. For epoxy coating repairs, it is noteworthy that, in order to prevent pit expansion, pitting depths up to 15% of the plate thickness are advised by class society norms. For distributed pitting depth up to 33 percent plate with small diameter with low pit density less than 20 percent area is suitable for belzona epoxy paint putty and coat. However, it is advised that weld infill and coating be used to repair deep pits that are more than 33% thick, or smaller diameter pits that are less than 300 mm. Additionally, composite cold work repairs or crop and renew are advised if the average remaining thickness for the pitted area is more than 50% of the as-built plate thickness.

Similarly, a crop and renew mitigation plan is advised for residual thicknesses that are less than or greater than 33% of as-built, such as big diameter pits or high pit density. Lastly, crop and renew mitigation is advised for plates with fewer than 6 mm of residual thickness. An SPM calm buoy plan view with manholes to compartments and ballast tanks is shown in Figure (6).

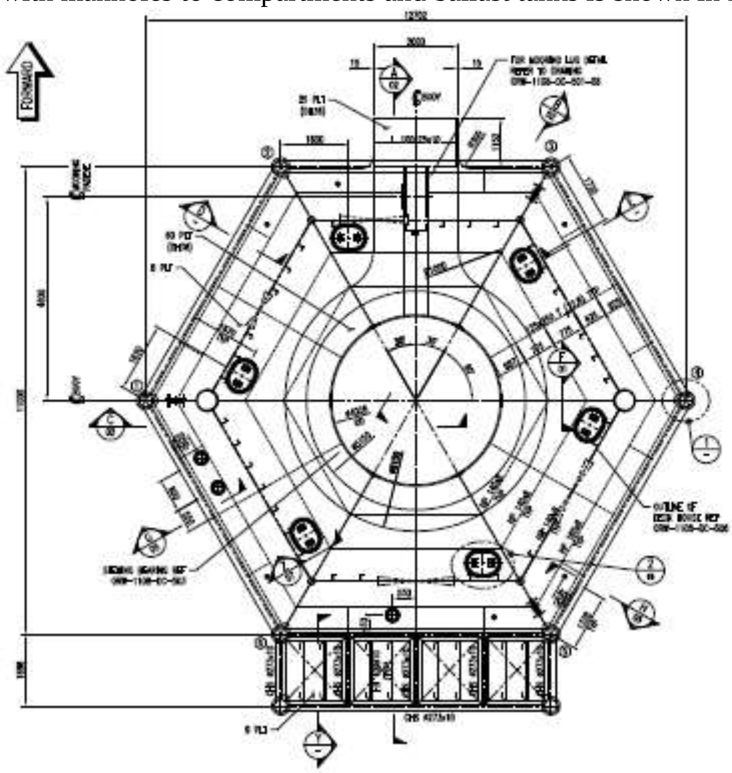

Figure (6): An SPM calm buoy plan view showing manholes to ballast tanks and compartments [63]

Maintenance, Repairs and Mitigation Strategies

When implemented correctly and to the satisfaction of the classification society that covers the floater, all of these mitigating methods are also practical ways to prolong the life of the floaters. The majority of floating industrial installations across the globe are either approaching or have already passed the end of their design life. These days, maintaining the safety and dependability of floating facilities to a specific level or higher necessitates the establishment of an appropriate, economical maintenance plan. In light of this, several factors to take into account when devising repair plans for structural elements thought to have sustained significant corrosion and fatigue cracking damage are now described [7]. According to [40], an ageing ship's longitudinal strength and, in fact, ship-shaped floating facilities must be maintained at least 90% of their original state [6], [39]. The current illustrated examples are extended as a device to construct a more complex maintenance plan based on hull girder ultimate strength, even though the IMO requirement is actually based on the floaters section modulus [40], [6]. According to research by [64], the shown strategy's goal is to ensure that an ageing floater's final hull girder strength always equals at least 90% of its original, as-built floater value [65]. The artists claim that instead of using member thickness as is customary, the renewal criterion for each damaged member is based on the member's ultimate strength [65]. According to the authors, this idea is beneficial because, while member thickness-based renewal criteria may manage the thickness reduction effects of general corrosion fairly well, they are unable to sufficiently reveal the effects of pitting corrosion, fatigue cracking, or local dent damage [48]. However, structural members like deck plates that meet ultimate strength-based renewal criteria are acceptable and better suited to manage all kinds of structural damage [44], as indicated by [46]. It goes without saying that appropriate maintenance techniques can regulate the structural safety and dependability of ageing vessels [6], [7]. In order to better regulate the age-dependent degradation of a floater longitudinal strength, the scientists indicated that the repair criterion based on member ultimate strength can offer a potential improvement [64]. The illustrations show that the percentage reduction in critical ultimate strength of structural members, like plates that require repair, is not constant as might be expected and is between 2 and 7 percent of the as-built state [66], [36], according to [49], [6]. Due to their exposure to harsh environmental conditions, the hull main deck plates of FPSO and SPM calm buoy floaters are susceptible to corrosion and structural damage. [67] states that when the thickness of the corroded main deck plating falls below the limitation values of the classification society that covers such a floater, it must be replaced in order to preserve the integrity of the floater [68]. Remarkably, the topside process modules are located in the main deck of a floater [67], [69]. But according to [6], these modules are utilised to manage, treat, and process the gas and oil extracted from subsea wells to the appropriate quality. However, the equipment used for process handling and treatment typically ages as a result of corrosion and wear and tear, and there is a chance that volatile flammable gases could leak or spill from the equipment, pipes, valves, or storage tanks. Two approaches are typically contrasted in order to reach a final conclusion during life extension structural inspections, evaluations, and recommendations for repairs and replacements. They are:

(a) On-site (In-situ)
(b) Dry Docks

On-site or in-situ repairs prevent or lessen the likelihood of lost production opportunities while enabling continuous production operations. Because it reduces or is linked to little downtime expenses, the on-site approach is growing in popularity. However, more extensive repairs are made possible by the dry docking technique. Although dry docking is very expensive, it typically saves money over time by lowering the need for regular repairs in the future. This is due to dry docking's unhindered access to all FPSO zones, including the cofferdam, cargo tanks, and hazardous zones, which makes repairs more thorough and practical. However, dry docking makes repairs more precise and comprehensive, which reduces the likelihood that such technical issues will arise anytime soon. Operators and owners plan and schedule turnaround maintenance, or TAM, every four years to coincide with the year before the certificate of class renewal survey in the absence of dry docks FPSOs. Typically, the TAM window is linked to a scheduled closure and the loss of production opportunities for a predetermined amount of time. A third-party inspection contractor licensed and approved by the classification society covering such floaters is used to open and check the cargo tanks during this time by a variety of suppliers, vendors, and the classification society. During this TAM period, the SPM calm buoy may be detached, towed to the ship yard for maintenance and repairs, and then towed back to the field to be reconnected. There the following points favours dry docking method:

(a) Reduced cost
(b) Enhanced quality
(c) Better accessibility

A growing number of FPSO/SPM calm buoy units are approaching the end of their design life, which creates a number of asset integrity issues [70], [68]. Costly structural repair procedures in harsh sea circumstances are occasionally required because corrosion wastage damages FPSO/SPM calm buoy hull structures such deck plates. Crop and renew procedures are often labour-intensive processes that necessitate dry docking. An FPSO must essentially remain offshore in their location due to the nature of production operations, which presents a number of operational, safety, and financial issues [25]. However, depending on the area where such hot work will be performed, the use of conventional hot work techniques, like welding or grinding, poses a risk to operational safety of lives and assets and ultimately results in a loss of production opportunity due to the storage of volatile and flammable liquids onboard [71]. There are harzadous and non-harzadous zones since FPSO are typically organised in zones. According to [70], the risk would be to perform these repairs offshore while maintaining strict safety regulations and preventing the loss of production opportunities. Cold work in-situ techniques that ensure safe and cost-effective hull plate repair are preferred by FPSO owners and operators [68], [72].

According to [68], if FPSO hull repair is required, economic considerations require that the FPSO be repaired on-site whenever feasible to minimise any lost production opportunities [71]. Therefore, any repairs to an FPSO's hull bottom problems must be done underwater [73]. Attaching an enclosed dam to the floater's underbelly, pumping out the water, and then finishing the repair from the inside is the recommended method [68]. However, wet underwater welding may be required to finish the welded repair from inside the vessel in cases where there is a risk of fire, explosion, or ballast issues [74]. Remedial measures including maintenance, repair, or steel renewal are planned using survey data. A systematic plan is designed to maintain the safety and integrity of structural components and hull girders to the required levels in order to avoid financial cost [6]. Classification societies offer helpful strategies for FPSO/SPM calm buoy upkeep and repairs [25]. In order to successfully maintain and repair an FPSO/SPM calm buoy, the following needs to be provided in accordance with the established standard:

(a) Carry out in situ repair without departing the field or dry-docking.
(b) Carry out repair that affects only the target area without functional stoppage or interruption to the production storage areas and offloading in other areas.
(c) Carry out repair without hot work, such as cutting or welding.
(d) Strategic and cost-effective repair.
(e) Carry out repair using easy-to-apply and readily/locally available technologies and personnel and.
(f) Carry out reliable repair methods backed up by a large amount of experience.

The following are the existing repair and replacement methods available for hull deck plates:

(a) Protective paint coating method
(b) Weld infill method
(c) Crop and weld or hot work method
(d) Adhesive patches method
(e) Sandwich plate system method

According to [6], a floater must stop production, travel to a repair yard, undergo dry-docking for repairs, return to the field, and be recommissioned if large portions of it need to be repaired by welding [7]. This could take many months, depending on the amount of labour, the resources available, and the availability of supplies. However, waiting for calm weather conditions is frequently necessary to do on-site welding repairs on small sections of a floater. This process entails a brief production stoppage, repair, and then a restart of output [75]. However, because of planning uncertainty, even minor repairs could take weeks. According to a group of academics, adding extra structural design safety margins at the beginning of construction is the greatest approach to reduce the need for costly on-site repairs [6]. Given their five-year dry docking duration, the authors clarified that these margins have to be as high as feasible and far greater than those of shuttle tankers [48]. In non-hazardous locations, such as water ballast tanks, it is typically used for deck plate repairs. According to [68], adhesive patches provide an alternative to welding-based repair techniques [70]. Notably, there is no fire risk because these are applied without hot labour [68]. For instance, to reinforce and bridge corroded or cracked regions, composite fiber-reinforced plastic patches can be laminated over structures or bonded [6], [70]. Inadequately bonded components may gather cargo and gas, and such adhesive patching may not be able to restore the lost strength [70], [7]. It's interesting to note that adhesive patches might stop leaks caused by corrosion [76]. Composite patch-based repair techniques should be taken into consideration for repairing damage on FPSO since they have been effectively used on service naval ships, bridges, and other facilities [70], [6].

The sandwich plate system (SPS), which is made up of two metal plates adhered to a small elastomer core, is another innovative repair technique [69]. The elastomer prevents local plate buckling, gives the plates constant support, and does away with the necessity for stiffeners [6]. According to [70], the SPS can be utilised in place of traditional stiffened steel plates in mechanical, civil, offshore, and naval engineering structures. Additionally, the SPS is utilised for repair and modification [69]. In this process, a new top plate is bonded to an old structure using the SPS overlay in a reasonably quick and cost-effective manner. Although the necessary levels of shear strength and fatigue performance are still to be attained in routine practice. Although [68] demonstrated that SPS technology is certified by multiple classification societies and is increasingly being utilised in the construction of new barges and the repair of parallel mid-body-damaged hull parts. SPS was created by SPS Technology, which is the top global provider of structural composite solutions for the maritime and offshore sectors [67]. First patented in 1996, SPS is a well-established and tested cold repair technology solution for the offshore and maritime industries. As a result, SPS has almost 25 years of market experience.

The P&O Pride of Cherbourg, a Lloyd's register-classified vessel, was the site of the first successful project utilising SPS in 1999. Conoco Phillips FPSO Independences had the first cold work application on-site in 2003. Typically, hot operations like welding and cropping is needed to replace the steel plating on floaters. Hazards of fire or explosion may arise from this, particularly if nearby flammable liquids or gases are leaking. However, FPSO main deck hot work may necessitate a lengthy planning and preparation phase, as well as an installation and survey period. However, depending on where the corroded deck plates are located, hot work may also disrupt the FPSO's regular output, which over time may have an impact on its daily production capacity and income creation. However, the considerations of performing hot work on the main deck of the FPSO may also need the use of additional personnel and supplies.

Applying cold repair techniques, such the sandwich plate system (SPS), which do not require hot labour and have a number of advantages over traditional procedures, is one potential classification society-recommended substitute [67]. The offshore and maritime industries are showing great interest in and acceptance of SPS composite repair technology for FPSO [67], [69]. However, in order to satisfy the needs and concerns of the offshore and maritime industries, cold repair technology is continuously evolving [72]. To improve the functionality, robustness, and dependability of composite repair solutions, new products are being created [67]. Figure (7) depicts the FSO Abu cluster's corroded deck plate being repaired, while Figure (8) shows a composite repair on the FPSO main deck plate. SPS is usually adopted for deck plate repairs in hazardous areas like cargo tanks. The FSO Abu Cluster's rusted deck plate has been repaired, as seen. The deck plate prior to repair is shown in the inset.

Figure (7): Repair of the corroded deck plate of the FSO Abu Cluster [70].

Figure (8): Composite repairs on FPSO main deck plate [67]

For FPSO main deck repairs, SPS procedures offer a number of benefits over conventional hot work methods. Among these benefits are:

(a) Safety: SPS repair techniques do not need hot work in dangerous locations, like those handling highly flammable materials, gases, liquids, or cargo. As a result, it lowers the possibility of an explosion, fire, or environmental and human harm. Since all cold repair work is done on the main deck without entering the tank, SPS cold work solutions reduce or eliminate the need for confined space entry.
(b) Time: Compared to traditional methods, SPS repair techniques require less time for design, preparation, installation, and surveying. SPS can be set up without interfering with the FPSO's regular production operation and while other tasks are still in progress. Additionally, SPS techniques do away with the necessity of tank cleaning, which may be expensive and time-consuming. Remarkably, the onshore workshop fabricates all of the SPS face plates and perimeter bar. As a result, it has shortened the onboard process schedule.
(c) Cost: Compared to traditional procedures, SPS repair techniques use less labour and material. When compared to crop and renew methods, SPS can save up to 90% of labour and 56% of steel. Therefore, by prolonging its service life and improving its performance, the SPS repairs approach can also lower the FPSO's maintenance and operating costs. However, as most fabrication work is done onshore, the number of people needed on board for SPS maintenance is significantly decreased.
(d) Quality: SPS repair methods offer a long-lasting, class-approved fix that restores or enhances the FPSO's structural integrity and durability. However, SPS can also offer better defence against explosion, impact, fatigue, and corrosion. As a result, SPS can offer FPSO main deck repairs in a quick, safe, affordable, and high-quality manner. Remarkably, SPS has been used in more than 500 projects in the offshore oil and gas and maritime sectors and has been accepted by all of the main classification bodies.

Even with preventative measures in place, the majority of FPSO/SPM calm buoys in operation suffer from some degree of corrosion [31]. Damaged protective coatings or insufficient cathodic protection voltage regulation are the causes of some of the occurrences that have been looked into [25], [32]. However, it is crucial to conduct a comprehensive evaluation of the extent of corrosion before putting mitigating measures into place [77]. The corrosion degree analysis may, however, reveal that the corroded part or region still possesses adequate strength for all pertinent limit states [78]. However, in these situations, cleaning, sandblasting, and reapplying a protective coating will be adequate to stop more corrosion [79]. Interestingly, corrective action is necessary if the study reveals that the corrosion degradation and deterioration are more severe. Notably, [80] stated that the following are practices used by the offshore industry to mitigate the damage caused by corrosion breakdown, failure, degradation, deterioration, and corrosion protection systems:

(a) Repair of damaged coatings
(b) Replacement of material and
(c) Repair or replacement of the corrosion protection system.

Since protective coatings serve as the main barriers separating the hulls of floating assets like FPSO/SPM calm buoys from the corrosive maritime environment, they are utilised to prevent corrosion on these assets. It is possible to apply marine protective coatings offshore, in a shipyard, a dockyard, or a construction yard. However, offshore coating projects are costlier, time-consuming, and frequently less successful. However, passive fire prevention, epoxy resins, and coal tar epoxy are the common coatings utilised offshore [81]. The external hull structures of FPSO/SPM calm buoys are the primary areas coated. Depending on the extent of deterioration, breakdown, or damage, coatings that are inspected as part of a survey program may need to be repaired or replaced. According to [49], there are a number of scales for determining the degree of damage that protective coatings may sustain, including blistering, rusting, flaking, and cracking. According to a 2005 study by Ersdal, one of the most prevalent forms of coating failure or breakdown, mostly brought on by ageing, is pin point or spot rusting. It can be challenging to determine the extent of coating layer deterioration during surveys without removing the coating, which can be costly and necessitate extensive repair work [31], [49]. According to [82], coating maintenance plans must incorporate appropriate brushing or water jet cleaning of the FPSO/SPM calm buoy hull surface in order to remove marine vegetation. Furthermore, before reapplying some protective coatings, the surface must be sandblasted to remove any damaged, deteriorated, or deteriorating coatings and to guarantee proper adhesion [83], [84, [85]. Although a favourable atmosphere is necessary to carry out the protective coating repair more successfully, [86] noted that certain protective coatings are available that may be manually applied underwater with effective adherence. It's interesting to note that ROVs are mostly utilised for pipeline repairs, but they can also function and do repairs underwater [31].

Access issues and the need to apply a coating to a wet surface arise when replacing coatings in the splash zone of floating offshore structures [87], [88]. Special coatings are needed to achieve high-quality adhesion in the splash zones [66], [36]. Coatings and anodes are crucial methods of preventing corrosion in ballast tanks in floating installations, such as FPSO/SPM calm buoys, as noted in [89]. In severe situations, localised corrosion and ultimately loss of watertight integrity on FPSO/SPM calm buoy tank compartments may result from the deterioration, breakdown, damage, or collapse of these protective coatings. An important corrosion mitigation strategy is to conduct regular and ongoing surveys, followed by careful planning and appropriate re-application of protective coatings in such sensitive areas.

Replacement of material, such as deck plate strakes for FPSO/SPM calm buoys when field application and usage restriction parameters are surpassed, is a more thorough approach to corrosion degradation and deterioration. This indicates that certain grade new material or alternatives, like sandwich plate system (epoxy) for deck plates, must be used to replace the hull deck plate zones or strakes entirely or in part. The following methods are frequently employed while replacing steel plates, per [31]:

(a) Insert plates
(b) Buttering and
(c) Doubler plates.

These techniques are used when zones or strakes is so severely corroded beyond the limiting minimum thickness that it is considered that complete zone or strake replacement is the most appropriate solution. Usually, the class society will carry out due diligence on the steel plate by checking the work order and heat numbers, grade on the mill test certificate and report. Furthermore, review the welding processes, welders certificate and verify the steel plate on site to ascertain that the information captured on the mill test certificate are stamped on the steel plate. Interesting, class society insist on grade for grade steel plate to repair corroded strakes or zones to prevent exposure to galvanic corrosion in the nearest future.

Similarly, classed vessels/floaters must be repaired with classed steel plates.

(a) Notably, insert plates for FPSO/SPM calm buoy repairs are primarily used to return the strake(s) or zone(s) to its original state. However, thicker insert plates than the original can be used to increase the plate thickness thereby obtaining a larger corrosion allowance for further operation [36], [32].
(b) Weld beads can be added to replace lost FPSO/SPM calm buoy hull deck plates material and is called buttering [25]. It is considered a good option in cases where the plate strakes of reduced thickness are limited such as pitting corrosion and where corrosion is limited to zones adjacent to welds [79].
(c) Doubler plates can be welded to a plate or member to increase thickness [78]. The introduction and consequent application of doubler plates in FPSO/SPM calm buoy hull deck plates repairs is primarily considered as a temporary measure but can occasionally be applied as permanent strengthening [31], [66].

FPSO/SPM calm buoys can be protected from corrosion using ICCP systems or sacrificial anodes. Sacrificial anodes are chosen based on their predicted lifespan, which is usually 20 to 30 years and proportionate to the FPSO/SPM calm buoy design life. In order to meet the system's anticipated current demand over the anticipated service life, sacrificial anodes are chosen. The cathodic potential and anode condition are analysed as part of the survey procedure. However, replacement can be advised based on the amount of anode material left. A sequence of drawings of sacrificial anodes with increasing material loss is displayed in Figure (9).

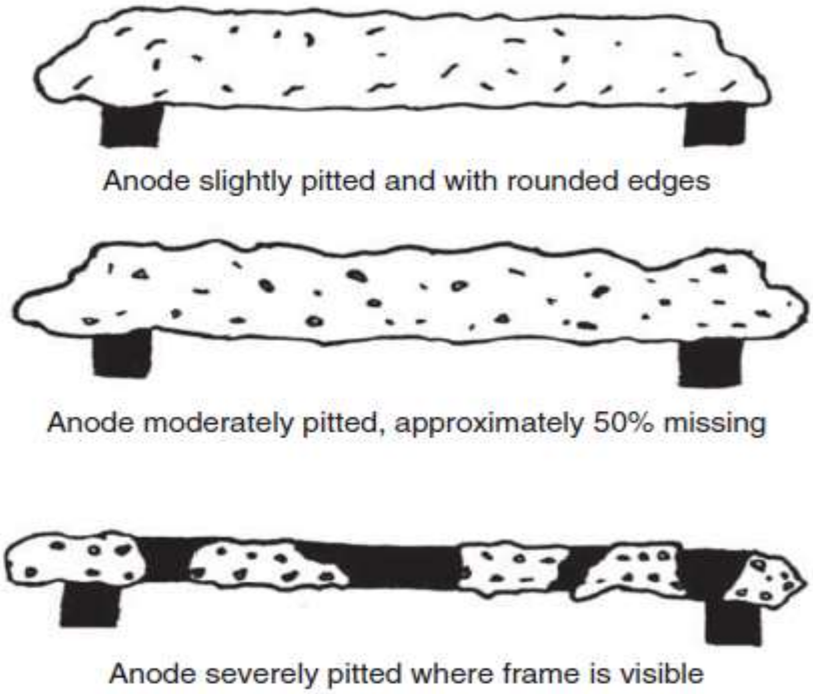

Figure (9): A series of drawings of sacrificial anodes with increasing loss of material [30].

The loss of sacrificial anode material at extreme stages, like the above badly pitted example, leads to a lower negative protection potential and, hence, less effective cathodic protection [31]. To ensure effective protection at this point, anode replacement is advised [25]. While it is possible to replace individual anodes, doing so may need many hours of underwater labour, typically using divers or ROVs. Choosing a corrosion protection system for floating facilities is done such that the system's planned life matches the operational or service life of the offshore installation. In order to meet the extended life, life extension procedures necessitate a comprehensive evaluation of these systems and the assessment of any necessary remedial or mitigating measures. Figure (10) represents the required mechanical properties of steels grades for marine plates renewal applications.

Grade	Elastic modulus, E (GPa)	Yield stress, σ_Y (MPa)	Ultimate tensile stress, σ_T (MPa)	Fracture (failure) strain, ε_f
A B D E	$\geq$ 200	$\geq$235	400–520	$\geq$0.22
AH32 DH32 EH32 FH32	$\geq$200	$\geq$315	440–570	$\geq$0.22
AH36 DH36 EH36 FH36	$\geq$200	$\geq$355	490–630	$\geq$0.21
AH40 DH40 EH40 FH40	$\geq$200	$\geq$390	510–660	$\geq$0.20

mechanical properties of steels grades for marine plates renewal applications [91].

CONCLUSION

Every floating facility, including FPSO and SPM calm buoys, goes through the inception, maturity, ageing, and terminal stages as it transitions from design life to end of service life. However, a number of inspections, repairs, and maintenance strategies have been implemented to support the FPSO and SPM calm buoy in fulfilling their intended lifespan. It's interesting to note that operations in an offshore or maritime environment will undoubtedly cause a floater to age. It should be mentioned, nevertheless, that improper management and maintenance of the floater may cause ageing to begin early. Operators would rather prolong the life of FPSO and SPM calm buoys than buy new ones due to OPEX and CAPEX considerations. Using the floating facility beyond its initial operational design life is referred to as "life extension." By presenting a business case, operators can make a solid decision on future or further use at the end of a life extension feasibility study or assessment process. This decision's technical component needs to answer issues like whether the facility is suitable for its intended use. The decision of whether to continue using a floating facility for life extension or decommission it is frequently based on whether an economic case for life extension can be made and whether a combination of mitigating actions and structural refurbishment, modifications, and upgrades will be adequate to demonstrate regulatory compliance with national safety and classification society requirements/satisfaction.

REFERENCES

[1] Machado, C.L. & Chand, S. (2013). Structural Impact in FPSO Life Extension: A Class Perspective. Proceedings of OMAE, 2013. OMAE 2013 – 10894. P.1. https://doi.org/10.1115/OMAE2013-10894

[2] Wang, X. & Sun, H. (2014). Structural Integrity Assessment of FPSO Life Extension and Relocation. Proceedings of OTC 2014, OTC-25311-MS, Houston Texas, 30 April – 3 May, 2014. Pp. 1-3.

[3] Machado, C.L., Wu, J. & Huang, W. (2015). Classification Society Studies on FPSO Life Extension Requirements. Proceedings of OTC2015, OTC-26202-MS, Rio de Janeiro, Brazil, 27-29 October, 2015. Pp. 1-2.

[4] Boutrot, J., Giorgiutti, Y., Rezende, F. & Barras, S. (2017). Reliable and Accurate Determination of Life Extension for Offshore Units. Proceedings of Offshore Technology Conference, OTC 2017, OTC-27547-MS, Houston Texas, USA, 1-4 May, 2017. Pp. 1-3.

[5] Ugbelasse, J.O., Osadebe, S., Bhat, S., Adegoke, A., Nnoaham, I., & Okwuosah, S. (2024). Bonga Main Life Extension Project: An In-Situ Life Extension of an FPSO Using FAIR+ER Methodology and Digital Twin Technology as Basis for Scope Identification and Definition. Shell Nigeria Exploration and Production Company, Proceedings of Offshore Technology Conference, OTC-35112-MS, OTC Houston Texas, USA, 6 – 9 May, 2024. Pp. 1-14. DOI 10.4043/35112-MS

[6] Paik, J.K. & Thayamballi, A.K. (2007). *Ship-Shaped Offshore Installations- Design, Building and Operations*. 1st Edition, Cambridge University Press, United Kingdom. Pp 1-536.

[7] Paik, J.K. (2022). *Ship-Shaped Offshore Installations- Design, Construction, Operations, Health Care and Decommissioning*. 2nd Edition, Cambridge University Press, United Kingdom. Pp 1-547.

[8] Sumpter, J. D. G., & Kent, J. S. (2004). Prediction of Ship Brittle Fracture Casualty Rates by a Probabilistic Method. *Marine Structures*, *17*. Pp. 575–589.

[9] TSCF (1992). *Condition Evaluation and Maintenance of Tanker Structures*. Tanker Structures Co-operative Forum, London: Witherby and Co. Ltd. P.6

[10] Hu, Y., Cui, W. & Pedersen, P.T. (2004). Maintained Ship Hull Girder Ultimate Strength Reliability Considering Corrosion and Fatigue, *Marine Structures*, 17:2, Pp. 91-123.

[11] Panayotova, M., Garbatov, Y. & Guedes Soares, C. (2004a). Factor Influencing Corrosion of Steel Structural Elements Immersed in Seawater, *International Conference on Marine Science and Technology*, Pp. 280-286.

[12] Panayotova, M., Garbatov, Y. & Guedes Soares, C., (2004b). Factor Influencing Atmospheric Corrosion and Corrosion in Closed Spaces of Marine Steel Structures, *International Conference on Marine Science and Technology*, Pp. 286-292.

[13] Panayotova, M., Garbatov, Y. & Guedes Soares, C. (2007). Corrosion Monitoring of Ship Hulls, *International Congress of Maritime Association of Mediterranean Conference Maritime Industry, Ocean Engineering and Coastal Resources*, Varna, Bulgaria,2 – 6 September 2007. Pp. 1-9.

[14] RINA (2004). *Guide for the Structural Design of Oil Tankers*, Registro Italiano Navale,Genova, Italy. P.6

[15] IACS (2005). *Common Structural Rules for Tankers and Bulk Carriers*. International Association of Classification Societies, London, UK. Pp. 1-7.

[16] Wang, G., Spenser, J. & Elsayed, T., (2003a). Estimation of Corrosion Rates of Oil Tankers, *International Conference on Offshore Mechanics and Arctic Engineering*, Cancun, Mexico. 2003. Pp. 1-4.

[17] Wang, G., Spencer, J., & Sun, H. (2003b). Assessment of Corrosion Risks to Ageing Ships Using an Experience Database. *22nd International Conference on Offshore Mechanics and Arctic Engineering, 2003*. Pp. 1-8.

[18] Yamamoto, N. & Kobayashi, H. (2005). Prediction System of Corrosion Progress on Ship Structural Members, *International Conference on Structural Safety and Reliability*, Rotterdam, the Netherlands. P. 10.

[19] Paik, J. & Melchers, R. (2008). *Condition Assessment of Aging Structures*, Woodheadublishing Ltd. Pp. 1-5.

[20] Boon, B., Buisman, B.C., Luijendijk, T. & Vonk, R. (1997). Mechanical Properties ofAged Ship Structures, *International Conference Ships – the Ageing Process*,London, UK. Pp. 3-8.

[21] Yamamoto, N. (2008a). Probabilistic Model of Pitting Corrosion and the Simulation ofPitted Corroded Condition, *International Conference on Offshore Mechanics andArctic Engineering*, Estoril, Portugal. Pp. 3=7.

[22] Akpanyung, K.V. & Loto, R.T. (2019). Pitting Corrosion Evaluation: A Review, Department of Mechanical Engineering, Covenant University, P.M.B 1023, Ota, Ogun State, Nigeria. *International Conference on Engineering for Sustainable World*. J. Phys.: Conf. Ser. 1378 022088, doi:10.1088/1742-6596/1378/2/022088. Pp. 1-9.

[23] Chernov, B. B. (1990). Predicting the Corrosion of Steels in Seawater from its Physiochemical Characteristics. *Protection of Metals*, 26(2). Pp. 238–241.

[24] Devanney, J. (2006). The Tankship Tromedy: The Impending Disasters in Tankers. *Tavernier, FL: Center for Tankship Excellence (CTX) Press*. P. 6.

[25] Ersdal, G. (2014). *Ageing and life extension of structures*. Compendium at the University of Stavanger. Pp. 1-50.

[26] Ophori, O.A., Briggs, T.A., & Diemuodeke, E.O. (2020). Cost Optimisation of Mooring Systems for Offshore Floating Platforms in Deep Water, Offshore Technology Institute, University of Port Harcourt. *European Journal of Mechanical Engineering Research, Vol. 7, No. 1*. P. 2

[27] Boggs, D., Barton, C., Albaugh, E. K. & Davis, D. (2021). 2021 Worldwide Survey of Floating Production, Storage and Offloading (FPSO) Units'. *Offshore Magazine / Endeavor Business Media*, Houston, TX, July/August. Pp. 5-8.

[28] Perera, D. Y. (1995). Stress Phenomena in Organic Coatings. *Paint and Coating Testingmanual. Gardner–Sward Handbook. Philadelphia: American Society for Testing andMaterials*. Pp. 1-5.

[29] Gordon, R.B., Brown, M.G., & Allen, E.M. (2014). Mooring Integrity Management: A State-of-the-Art Review, DNV GL. Offshore Technology Conference, OTC 25134, Houston, Texas, USA, 5–8 May 2014. DOI: 10.4043/25134-MS. Pp. 1-9

[30] Ersdal, G., Sharp, J.V. & Stacey, A. (2019). *Ageing and Life Extension of Offshore Structures: The Challenges of Managing Structural Integrity*. 1st Edition, John Wiley and Sons Publishers, United Kingdom. Pp. 1-190.

[31] Sharp, J.V. & Ersdal, G. (2021). Underwater Inspection and Repairs for Offshore Structures. *1st Edition, John Wiley and Sons Publishers, United Kingdom*. Pp. 1-348.

[32] Ersdal, G. (2005). Assessment of Existing Offshore Structures for Life Extension. *Doctor Thesis, University of Stavanger*. October 2005. Pp. 1-200

[33] Stacey, A. (2010). HSE Ageing and Life Extension Inspection Programme. *Presentation at the Norwegian Petroleum Safety Authority Workshop on Ageing and Life Extension, PSA, Norway (7 April 2010)*. Pp. 1-8.

[34] Sharp, J.V., Wintle, J.B., Johnston, C., & Stacey, A. (2011). Industry Practices for the Management of Ageing Assets Relevant to Offshore Installations. *Paper no. OMAE2011–49264*. Pp. 1-9.

[35] Ersdal, G. & Selnes, P.O. (2010). Life Extension of Aging Petroleum Production Facilities Offshore. *SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production*, 12–14 April, 2010. Rio de Janeiro, Brazil, Pp. 1–14.

[36] ABS (2018a). *Rules for Building and Classing Floating Production Installations*. American Bureau of Shipping, July, 2018. Pp. 1-12.

[38] ABS (2021). *Guidance Notes on Life Extension Methodology for Floating Production Installations*. Pp. 1-51. American Bureau of Shipping, July, 2021. Pp. 1-20.

[39] IMO (2000). SOLAS /2 *Recommended Longitudinal Strength*. (MSC.108(73)), Maritime Safety Committee, International Maritime Organization, London. Pp. 2-5.

[40] IMO (2006). *Guidelines for Performance Standard for Protective Coating MSC.215(82) Resolution*, International Maritime Organization. Pp. 1-7.

[41] ABS (2015). *Guidance Notes on Life Extension Methodology for Floating Production Installations*. American Bureau of Shipping, July 2015. Pp. 1-14.

[42] Zuccarelli, F., Diamantidis, D., Righetti, G. & Valente, E. (1991). Lifetime Extension of Existing Offshore Structures. *Proceedings of 1st ISOPE Conference, Edinburgh.* Pp. 43-48.

[43] Wang, G., Spencer, J., & Elsayed, T., (2003c). Estimation of Corrosion Rates of Structural Members in Oil Tankers. *International Conference on Offshore Mechanics and Arctic Engineering, Cancun, Mexico, 2003*. Pp. 2-9.

[44] Paik, J. K. & Melchers, R. E. (2008). *Condition Assessment of Aged Structures*. CRC Press, New York. Pp. 1-9.

[45] Seo, S.S., Baek, K.K., Park, C.S., Lee, C.H. & Chung, M.K. (2007). Effect of Edge Preparation Methods on Edge Retention Rate of Epoxy Coatings for Ship's Ballast Tanks. *International Symposium on Shipbuilding Technology - Fabrication and Coatings*, Osaka, Japan, 6-7 September 2007. Pp. 1-9.

[46] Paik, J. K. & Kim, D. K. (2012). Advanced Method for the Development of an Empirical Model to Predict Time-Dependent Corrosion Wastage. *Corrosion Science*, *63*. Pp. 51–58.

[47] IACS (2006). *Recommendation 87 Guidelines for Coating Maintenance and Repairs for Ballast Tanks and Combined Cargo/Ballast Tanks on Tankers, Rev.1 June 2006*, International Association of Classification Societies, London, UK. Pp. 1-9.

[48] Park, S. H., Shin, H. K., Kim, J. S., Cho, S. R., Jang, Y. S., Baek, N. K. & Park, D. K. (2020). Experimental Investigations on the Residual Strength of Corroded Steel-Stiffened Plates. *Proceedings of the 39thInternational Conference on Ocean, Offshore and Arctic Engineering, OMAE2020-19122*. doi: 10.1115/OMAE2020-19122, 3–7 August (Online). Pp. 1-6.

[49] ISO (2016), *ISO 4628-3:2016 Paints and Varnishes—Evaluation of Degradation of Coatings*, International Organization for Standardization. Pp. 2-5.

[50] Osawa, N., Umemoto, K., Nambu, Y. & Kuramoto, T. (2007). Study on the Alternatives to the Secondary Surface Preparation in Protective Coatings, *International Symposium on Shipbuilding Technology - Fabrication and Coatings*, Osaka, Japan, 6-7 September 2007. Pp. 1-6.

[51] Guedes Soares, C. & Garbatov, Y. (1996). Reliability of Maintained Ship Hulls Subjected to Corrosion. *Journal of Ship Research 40 (3).* Pp. 235 – 243

[52] Sakashita, S., Tatsumi, A., Imamura, H. & Ikeda, H. (2007). Development of Anticorrosion Steel for the Bottom Plates of Cargo Oil Tanks. *International Symposium on Shipbuilding Technology - Fabrication and Coatings, Osaka, Japan, 6-7 September 2007*. Pp. 1-8.

[53] Melchers, R. E. (2002). Effect of Temperature on the Marine Immersion Corrosion of Carbon Steels. Corrosion, 2002. 58(9). Pp. 768–782.

[54] Gardiner, C. P., & Melchers, R. E. (1999). Enclosed Atmospheric Corrosion in an Unloaded Bulk Carrier Cargo Hold. *Proceedings of Australian Corrosion Congress* (Paper No. 45), Sydney, Australia, November, 1999. Pp. 4-8.

[55] Gardiner, C., & Melchers, R. E. (1998). Aspects of Bulk Carrier Hold Corrosion. *Proceedings of International Conference on the Design and Operation of Bulk Carriers* (Paper No. 7), The Royal Institution of Naval Architects, London. Pp. 1-6.

[56] Melchers, R. E. (2005). Effect of Nutrient-Based Water Pollution on the Corrosion of MildSteel in Marine Immersion Conditions. *Corrosion*, *61(3).* Pp. 237–245.

[57] Melchers, R. E., & Jeffrey, R. (2004). Surface Roughness Effect on Marine ImmersionCorrosion of Mild Steel. *Corrosion*, *60(7).* Pp. 697–703.

[58] Melchers, R. E. (1997). Modelling of Marine Corrosion of Steel Specimens. *CorrosionTesting in Natural Waters*. Vol. 2. R. M. Kain and W. T. Young, eds. Philadelphia: *AmericanSociety for Testing and Materials*. Pp. 20–33.

[59] IMO (2004). *Safety of life at sea (SOLAS): Consolidated Edition: International convention for the safety of life at sea*. International Maritime Organization, London. P.1.

[60] Seki, Y., Kondou, K. & Harada, O. (2007). The Third Generation Shop Primer and Japanese Shipbuilding Construction Process. *International Symposium on Shipbuilding Technology - Fabrication and Coatings*, Osaka, Japan, 6-7 September 2007. Pp. 1-7.

[61] Lanquetin, B., Rouhan, A. & Gourdet, G. (2007a). Risk-Based Inspection on FPSOs Hulls; Case Studies on New-Built Units, *Offshore Mediterranean Conference, Ravenna, Italy, 16-18 March 2005.* Pp. 1-7.

[62] Lanquetin, B., Goyet, J. & Esteve, J. (2007b). Implementing Risk-Based Inspection on our FPSOs: from a Practical Approach to the Edge of R and D. *Offshore Technology Conference, Houston TX, 30 April – 3 May 2007*. Pp. 1-8.

[63] Gordon, R.B. (2015). Considerations for Mooring Life Extension, DNV GL, Proceedings of the 20th Offshore Symposium, February 2015, Houston, Texas, Society of Naval Architects and Marine Engineers. Pp. 1 – 8

[64] Paik, J. K., Lee, J. M. & Ko, M. J. (2004). Ultimate Shear Strength of Plate Elements with Pit Corrosion Wastage. *Thin–Walled Structures*, *42(8).* Pp.1161–1176.

[65] TSCF (1992). *Condition Evaluation and Maintenance of Tanker Structures*. Tanker Structures Co-operative Forum, London: Witherby and Co. Ltd. P.6

[66]Belzona (2020). Solutions for Splash Zones. https://www.belzona.com/en/focus/splash_zones.aspx, Accessed on 23rd June 2020. Pp. 1-5.

[67] MOG (2023). MOG Technologies; Cold Work Repairs for Main Deck Reinstatement of FPSO. https://mog-tech.com. P. 1.

[68] Paillusseau, C., Errotabehere, X., Flora, V., Bulbaca, M., Pinto, G., & Galter, A., (2019). FPSO Hull Brackets Repair by Cold Bonded Reinforcements – Project Lessons Learnt from a World First Offshore West Africa. Cold Pad and SBM Offshore. *Offshore Technology Conference, OTC2019-29792-MS, Rio de Janeiro, Brazil, 29–31 October 2019*. Pp. 1-9.

[69] SPS (2005). *Sandwich plate system*. (www.ie-sps.com) accessed June 2006.P.1

[70] McGeorge, D., A.T. Echtermeyer, A.T., K.H. Leong, K.H., B. Melve, B., Robinson, M., & Fischer, K.P. (2009). Repair of Floating Offshore Units Using Bonded Fibre Composite Materials. Babcock Marine-Composites Group, Devonport Royal Dockyard, Plymouth PL1 4SG, United Kingdom. *Elsevier Journal of Composites: Part A 40 (2009).* Pp.1364–1380

[71] Weitzenböck, J.R. & McGeorge, D. (2004). The Designer's Dilemma: How to Deal with the Uncertainty About the Long Term Performance of Adhesively Bonded Joints. *J Proc Instn Mech Engrs M J Eng Marit Env 2004;218(M4)*. P.273.

[72] Marsh, G. (2006). Composites Keep Pipelines Flowing. *Reinf Plast 2006;50(3).* P. 34.

[73] Baker, A.A., Kelly, D.W., & Dutton, S.E. (2004). Composite Materials for Aircraft Structures. *2nd ed. VA, USA: American Institute of Aeronautics and Astronautics (AIAA), Reston*; 2004.Pp. 3-4.

[74] Echtermeyer, A.T., McGeorge, D., Sund, O.E., Andresen, H.W., & Fischer, K. P. (2005). Repair of FPSO with composite patches. *Presented at the Fourth International Conference on Composite Materials for Offshore Operations (CMOO-4), Houston, TX, USA*. 4–5 October 2005. Pp. 1-9.

[75] Andersen, H.W, & Echtermeyer, A.T., (2006). Critical Energy Release Rate for a CSM Reinforced Carbon Fibre Composite/Steel Bonding. *Comp A 2006;37(5).* P.742.

[76] Demsetz, L., Carlo, R., and Schulte-Strathaus, R. (1996). Inspection of Marine Structures. *Ship Structures Committee, SSC-389, Washington, DC.* Pp. 2-20.

[77] Si, X.S., Wang, W., Hu, C.H. & Zhou, D.H. (2011). Remaining useful life estimation - A review on the statistical data driven approaches. *European Journal of Operational Research*, 213(1), Pp.1–14.

[78] Stacey, A., Birkinshaw, M. & Sharp, J.V. (2008). Life extension issues for ageing offshore installations. *Proceedings of the 27th International Conference on Offshore Mechanics and Arctic Engineering (OMAE)*, June 15–20, Estoril, Portugal, Pp. 199–215.

[79] Paik, J. K. & Kim, D. K. (2012). Advanced Method for the Development of an Empirical Model to Predict Time-Dependent Corrosion Wastage. *Corrosion Science*, *63*. Pp. 51–58.

[80] Bahadori, A., (2014). Cathodic Corrosion Protection Systems—Guide for Oil and Gas Industries. *Gulf Professional Publishing, Elsevier Waltham*, Massachusetts, US. P. 6.
[81] Matsuda, M., Kobayashi, S., Miyuki, H. & Yoshida, S. (1999). An Anticorrosion Method for Ballast Tanks Using Nitrogen Gas. *Ship and Ocean Foundation, Tokyo*. P.5.
[82] LR (2003). *FPSO Inspection, Repair, and Maintenance – Study into Best Practice*. (R20821-5-UKOOA), Lloyd's Register, London, May, 2003. Pp. 1-5.
[83] Johnson, M. (1996). Application of the ABS/Safe Hull Technology to FPSO Conversions. *Presented at the Annual Meeting of the Texas Section, The Society of Naval Architects and Marine Engineers, Alexandria, VA, 23 February, 1996*. Pp. 1-5.
[84] Lambourne, R., & Strivens,T. A. (1999). Paint and Surface Coatings: Theory and Practice. Norwich, NY: William Andrew Publishing. Pp. 45-46.
[85] Rolli, M. S. (1995). A Reliable Method for Predicting Long-Term Coatings Performance. *Corrosion Management, 4(1).* Pp. 4–7.
[86] Melchers, R. E., & Jiang, X. (2006). Estimation of Models for Durability of Epoxy Coatings in Water Ballast Tanks. *Ships and Offshore Structures, 1(1).* Pp. 61–70.
[87] Craig, B. D., & Anderson, D. S. (1995). *Handbook of Corrosion Data* (Materials Data Series). 2nd Edition, Materials Park, OH, ASM International. Pp. 50-60.
[88] Scully, J. R., & Hensley, S. T. (1994). Lifetime Prediction for Organic Coatings on Steel and a Magnesium Alloy Using Electrochemical Impedance Methods. *Corrosion, 50(9).* Pp. 705–716.
[89] TSCF (1995). *Guidance for inspection and maintenance of double hull tanker structures*. Tanker Structures Co-operative Forum, London: Witherby and Co. Ltd. Pp. 2-7.
[90] Park, S. H., Shin, H. K., Kim, J. S., Cho, S. R., Jang, Y. S., Baek, N. K. & Park, D. K. (2020). Experimental Investigations on the Residual Strength of Corroded Steel-Stiffened Plates. *Proceedings of the 39thInternational Conference on Ocean, Offshore and Arctic Engineering, OMAE2020-19122*. doi: 10.1115/OMAE2020-19122, 3–7 August (Online). Pp. 1-6.
[91] IACS (2017). *Normal and Higher Strength Hull Structural Steels (UR W11)*. International Association of Classification Societies, London. Pp. 1-6.

LIST OF ABBREVIATIONS/SYMBOL

ABS - American Bureau of Shipping
APB - Acid Producing Bacteria
BV – Bureau Veritas
CAPEX – Capital Expenditure
CP – Cathodic Protection
CSR Common Structural Rules
DNV - Det Norsk Veritas
FPSO - Floating Production, Storage and Offloading
FSO - Floating Storage and Offloading
GoG - Gulf of Guinea
HSE – Health Safety and Environment
IACS – International Association of Classification Societies
ICCP – Impressed Current Cathodic Protection
IMO – International Maritime Organisation
ISO - International Standard Organization
ISSC - International Ship and Offshore Structures Congress
MOG – MOG Technologies
NDE – Non Destructive Examination
NDT – Non Destructive Testing

OPEX-Operating Expenditure
ROV - Remotely Operated Vehicle
SPM - Single Point Mooring
SPS – Sandwich Plate System
SRB - Sulfate Reducing Bacteria
TAM – Turnaround Maintenance
TSCF – Tanker Structures Cooperative Forum
UTM – Ultrasonic Thickness Measurement