ENHANCING SAFETY ON FPSOs:

PRACTICAL CONSIDERATIONS FOR OPERATIONS AND MAINTENANCE

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EXECUTIVE SUMMARY

INTRODUCTION

The global FPSO fleet is the most diverse it has ever been. As an industry that has existed for almost 50 years, the range of assets that are being managed is quite diverse. FPSOs of all sizes, ages, designs, and arrangements are in operation with dedicated teams of professionals committed to maintaining performance and safety.

At ABS, it is our mission to promote the safety of life, property, and preservation of the natural environment. This mission aligns well with the culture of the offshore oil production industry an especially well with that of those responsible for the successful operation of the global FPSO fleet.

Operations and maintenance challenges vary widely across the global fleet of FPSOs. With many assets well over 40 years since their keel laying date, hull integrity and maintenance require a large portion of the available maintenance resources. This commonly occurs when the field is in its later stage and operating margins are at their slimmest. Alternatively, newer FPSOs are some of the largest ever built and are equipped with the most modern, digital condition monitoring and maintenance systems. While the requirements for these units are similar, the challenges faced in operations and maintenance are quite different.

SHARING SOLUTIONS TO SUPPORT MAINTENANCE AND OPERATIONS

Opportunities to support FPSO operations and maintenance can be adopted from several different areas. These include procedural improvements, the application of new technologies, design improvements, and the utilization of digital solutions. In many instances preventative actions can be identified and implemented to prevent costly downtime and repairs. Often damage and required repairs are only identified after the fact. As the industry gains experience providing repair and maintenance solutions, these best practices should be shared to promote safe and successful offshore operations.

As an industry of responsible engineers, we are obligated to share what we learn through our experience to promote safety. As the leading class society in the FPSO market, ABS has a unique opportunity to partner with many different operators and observe, participate in and promote the best practices for maintenance offshore. Innovative risk based inspection (RBI), tank cleaning and repair procedures should be shared across the fleet and implemented as best suits the operating profile of FPSOs of all ages and designs.

Similarly, there are opportunities in the design and construction phase of projects to proactively address how design affects maintenance. For example, designing permanent means of access for more efficient tank inspections or designing tank internals to better accommodate crude oil washing (COW) and tank cleaning can have a significant impact on the cost and success of offshore operations.

In this publication, ABS has worked together with a number of offshore operators to share information on best practices that can be applied across a diverse FPSO fleet. FPSOs of all types can potentially improve their operations and maintenance practices by utilizing the practices described herein. By working together as an industry to apply new tools, practices, and technology, we can achieve our mission of safer and more effective performance offshore.

TANK DESIGN FOR CLEANING AND REMOTE INSPECTION

OVERVIEW

Classification rules and statutory requirements (Load Line, SOLAS/MODU Code as applicable, MARPOL Annex I) require the internal inspection of cargo tanks to verify that the structure remains in compliance with the applicable requirements with no unacceptable levels of wastage, pitting, fractures, etc. In addition, the tank boundaries are also required to be pressure tested to confirm structural integrity. Any findings noted to be in non-compliance with the requirements require remedial action to be satisfactorily addressed. All the foregoing requires safe and timely access to the tanks.

To facilitate the access to the cargo tanks for internal inspection, tanks need to be cleaned. Thorough tank cleaning can be very laborious and time-consuming, and require a large number of personnel to enter and work within the tanks to complete the demucking task. The primary method to clean cargo and slop tanks involves crude oil using high-pressure fixed crude oil washing (COW) machines installed within the cargo storage tank, followed by water washing through the COW machines, then manual removal of remaining sludge and waste demucking, and high-pressure water washing, along with draining to a slop tank for separation of oil and water.

This paper discusses the challenges, current methods, and immediate and future solutions/best practices related to crude oil tank design, cleaning, and inspection.

BENEFITS

Improving the design of crude oil tanks and the method in which they are cleaned has the potential to reduce downtime and risk to personnel by reducing or eliminating confined space entry for manual cleaning, reduce the sludge and sediment accumulation, prevent accumulation of naturally occurring radioactive material (NORM), improve tank surface inspection quality, increase visibility for remote inspection, and reduce the overall operating costs.

Reduce or Eliminate Tank Confined Space Entry
Safety is paramount and reducing or eliminating tank confined space entries can greatly decrease risk to personnel engaged in FPSO operations. For example, according to the article, “Enclosed space deaths onboard: Why do they persist?”, published by Safety4Sea in October 2020, an International Transport Workers Federation (ITF) report stated that over the last 20 years there have been 145 casualties in enclosed spaces onboard vessels with 28 incidents occurring in the last 16 months prior to publishing the report[1]. There are various incidents that can lead to death or injury during this process, so removing the need for personnel to enter a crude oil tank would be a milestone win for the industry.

Reduce Manpower and Time
Reducing the number of personnel needed to enter a tank for manual cleaning and inspection provides the greatest personnel risk reduction to an FPSO owner or operator. The cost of cleaning including number of personnel onboard, time needed and amount of waste for disposal could potentially be reduced as well.

Improve Tank Inspection Quality
Another major benefit of improving the design of FPSO crude oil storage tanks is the ability to reveal issues with structural components or coatings which are very important with a prioritized risk-based inspection (RBI) program. This is especially important in critical areas that may have previously been difficult to clean or view. The cleaner a tank is, the greater the ability a surveyor or inspector has to view coating conditions, potential structural defects, and critical areas. Improving the design of tanks and cleaning methods to remove or work around internal structure, cargo piping, and heating equipment from within a tank can lead to easier and increased cleanliness and inspection.

Increase Visibility for Remote Inspections
Reducing the amount of visual interference from internal tank structure and the remaining oil residue would increase visibility for remote inspection when taking photographs and 360-degree video, and would decrease the need to insert the camera and lower device into openings in order to get a complete picture of the tank. Decreased structural components and piping within the tanks would also allow for easier and faster operation of remote vehicles, such as UAVs and robotic crawlers used for close-up visual inspections.

CHALLENGES

Challenges can arise at any stage of FPSO operations and, it is important to try to mitigate them whenever possible. The preparation of a tank for safe access by personnel presents a challenge as FPSOs may remain on station for years without being dry-docked.

- Operators do not have access to infrastructure and equipment readily available in a shipyard.
- Conventional means of manual sludge removal by dedicated shore teams may not always be a viable option for FPSOs operating offshore.
- Accommodation capacities may be a constraint.
- Capacity limitations of boiler or other heating mediums used may not allow increase of cargo oil pump (COP) discharge flow for COW during offloading.
- Crew understanding of COW operations and criticality of the operation may not be adequate.

One challenge when cleaning and inspecting a crude oil storage tank is the obstructions and shadow areas presented by internal tank strength structures, piping, and access objects. Build-up of sediments, sludge and scale at the bottom of cargo tanks and on other horizontal surfaces is common in many FPSO tanks. Factors influencing the build-up include shape of the tank; internal tank structure (web frames, stringers and stiffeners); composition of the oil including paraffin's (wax) sediment (sand) and viscosity; tank coatings; and the frequency and effectiveness of COW and sludge removal performed during operations over the life of the asset. A meaningful close visual inspection of the tank surfaces requires the removal of this build-up of sludge and/or sediments. For existing vessels this challenge may not be easily overcome due to the high cost and time required to completely retrofit these tanks, but there are some potentially viable options, such as increasing the number of and location of fixed and mobile crude oil/water cleaning nozzles.

Cargo tank cleaning relies upon the competence of FPSO marine staff to use the systems onboard to carry out effective COW and water washing. This includes the periodic operation of the COW system in service to minimize tank sediments and the use of the system, with heating if required, to clean the tank as much as possible prior to entry and final demucking operations. However, no COW can fully clean a cargo tank and problems with process trains may mean that heavy sediments, such as sand and scale, which may include NORM, never leave the cargo tanks.

Another challenge is the handling of COW oil. When discharging COW oil along with export crude to an export tanker, there is a potential for excessive sediment collection in cargo custody metering strainers and a potential for metering instrument failures. This is one of the primary reasons FPSO operators are hesitant to discharge COW oil to export tankers. The opportunity to address the challenge of overall tank design, especially internal structure will come when new FPSO vessels are designed and built and could be similar to storage tanks found onboard chemical tankers.

CURRENT PRACTICES

TANK CLEANING

The current initial method of cleaning crude oil tanks on FPSO vessels is by utilizing permanently installed cleaning machines, such as COW nozzles, and using portable drop in tank cleaning machines and onboard personnel to complete the remaining in tank manual cleaning. While the goal is to reduce and hopefully eliminate the need for personnel to physically enter oil tanks, currently there are no other proven methods that do not require personnel to enter and manually clean (demuck) the tanks. According to IMO Resolution A.446(XI), permanent cleaning systems are required to be able to cover at least 90 percent of the horizontal areas and 85 percent of the vertical areas of the tank surface.

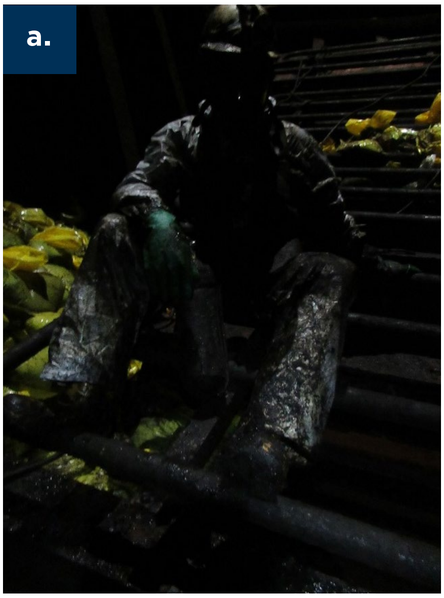
Remaining sludge after COW and water washing requires the need for personnel to enter the tank for manual removal, which can present personnel hazards of confined space entry, exposure to hydrocarbons trapped within the oil sludge, dropped objects, slip-trip-fall hazard of personnel entering/exiting and transiting over tank structures. Final manual demucking is a very labor intensive and time-consuming process.

Examples of current methods for tank cleaning are shown in the photos below:

a. Personnel in the tank performing manual cleaning and bagging,

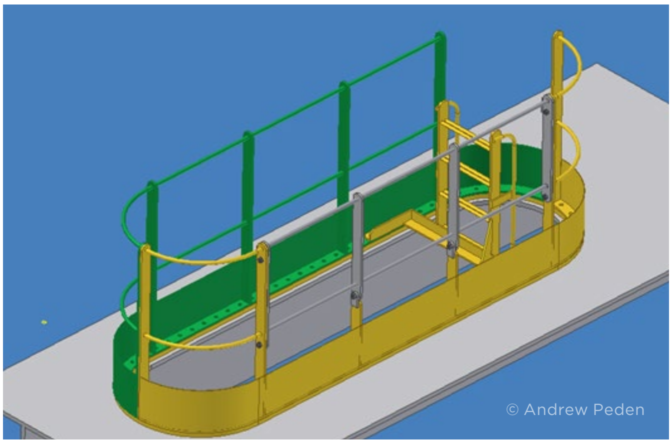
b. System for hoisting and removing sludge,

c. Temporary storage and transportation of bagged sludge.



Most Owners use a manual system to gather sediments that are trapped between bottom stiffeners (single hull units) into small bags, which are then collected and hoisted to the main deck using small hoists erected over existing manholes. This may be improved upon the use of vacuum systems and washing systems with slurry pumps, so long as the sediment is of a suitable consistency and density to allow this method.

Owners have been able to improve on this by cutting larger openings into the deck and fabricating portable lifting machinery designed especially for the opening to allow for movement of unitized skids for material, machinery, and injured personnel. Several owners have advised that they are now requiring 1000mm by 800 mm openings in their specifications for new units. One owner has developed a large opening suitable for use on existing units when work is required inside the tank. The photos below show the relatively large size of this Owner's opening along with fittings and equipment sized specifically for the opening.



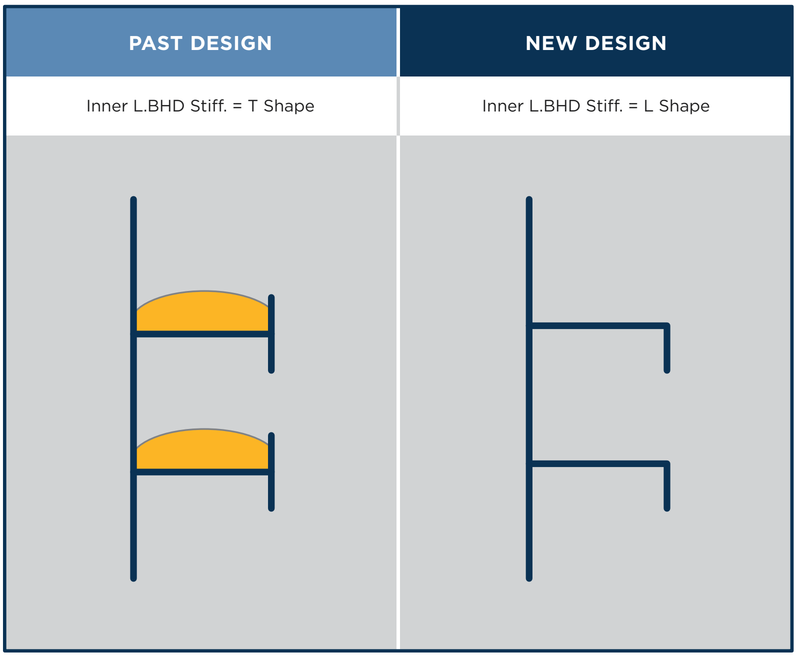
Operators of double hull FPSOs with limited structures in the cargo tanks (e.g., longitudinal corrugated bulkheads) may be able to clean some coated tanks sufficiently for an examination using only the COW system without the need for any personnel entry into the tank.

REMOTE INPSECTION

Remote inspection has been proven effective in existing ballast and void tanks of FPSOs when the unit has clean ballast water and tanks with good coating condition. ROVs are effective at examining flooded clean ballast tanks and can take thickness readings through coatings. However, this is not a preferred method for cargo tanks as the water is typically not clean enough and the operator will not want to fill the cargo tanks with water from a corrosion and waste oily water management perspective. Flying drones has been shown to be able to provide a visual survey, and some have started to also conduct ultrasonic gaugings. Existing cutouts in longitudinal girders and transverse frames are generally sufficient to accommodate small form factor ROVs and drones. However, if the tank has scale or other items that prevent an effective remote examination, some or all of the spaces may require examination by personnel. Planning the examination route in advance is required both for UAVs and ROVs to determine whether the entire tank is accessible, and tether management is required for ROVs to ensure the device can be removed from the tank.

BEST PRACTICES FOR COW AND SLUGE MANAMAGMENT

DESIGN ENHANCEMENT



- Stiffener profiles should be changed to minimize the deposit of sediments and to facilitate COW
- Tank suctions are to be preferably located at the center line of the tank. Alternatively, consideration may be given to a suitable list within the acceptable hull girder strength and stability parameters to facilitate flow towards the tank suctions or suctions in tank sumps if allowed for by double hull construction.
- Large sized limber holes through transverse and longitudinal framing so as to allow efficient cargo drainage to pump suction.

  Note: MARPOL requirements of a vessel in ballast condition which limits the vessel's trim to 0.015 L do not apply to the foregoing.
- MARPOL requirements for COW systems require a minimum of 85 percent vertical and 90 percent horizontal surface coverage. Consideration for additional COW machines during the design phase by a thorough shadow analysis is recommended to maximize the coverage, especially in way of bottom areas.
- Consideration of a COP system arrangement to run dedicated COP for COW during offloading
- Hydraulic pumps, in lieu of the conventional steam turbine pumps, with deep suction wells may enable better offtake of the crude oil with sludge at the bottom. Alternatively, the use of in-tank eductor stripping systems
- Cargo pump used for COW may have direct suction from clean slop tank, with the suction capacity large enough to not cause abnormal vibration due to cavitation.
- Consider remote control valves on COW branch lines to simultaneously control COP from Cargo Control Room (CCR) during offloading.
- It is recommended that adequate means of positively isolating the COW machines servicing one tank from the rest of the system be provided to enable maintenance and positive isolation for confined space entry.
- Arrangement of topsides should allow for the entire machine to be pulled and laid down. Approved temporary lifting arrangement may also be considered as an alternative. Another option to consider would be COW machines that can be removed in sections.

OPERATIONAL CONSIDERATION

COW OPERATIONS

- A schedule for COW operations, covering all storage tanks, should be developed taking into account crude oil properties and temperatures. Periodic reviews of the schedule should be carried out and adjustments made as necessary. Depending on crude quality, each storage tank is recommended to be crude oil washed at least annually.
- COW operations are to be carried out in accordance with the approved COW Manual at the minimum, that takes into account IMO Revised Specifications for the Design, Operation and Control of COW Systems (A.446 (XI)) as amended by resolutions A.497 (XII) and A.897 (21)).
- COW should also be undertaken in accordance with the guidance in International Safety Guide for Oil Tankers and Terminals (ISGOTT), Chapter 11 and OCIMF-Cargo Guidelines for F(P)SOs 1st Ed Section 7.
- COW should only be undertaken when the oxygen content of the tank atmosphere is maintained below 8 percent by volume, as per ISGOTT requirements. The oxygen content should be tested at multiple levels of the tank – lower, mid and upper.

- Operators should factor in a minimum inert gas system pressure during COW operations. Typical minimum limits are about 500 mm WG (millimeters of Water Gauge) but not less than 300 mm WG in any case. Similarly, maximum inert gas pressure is recommended to not exceed about 800 mm WG.
- Crude used for COW must be 'dry' to minimize static produced during the washing operation.
- It should be noted that in the case of waxy crude oils, continued washing with the same crude oil can lead to wax saturation and loss of solvency.
- In the case of high wax crude oils, it is found that, typically, instead of a full cycle, a COW program of 40 degrees to zero with an additional repeat operation may improve the efficiency and prevent further build-up on tank sides.
- To achieve effective stripping, the maximum possible stern trim, compatible with acceptable hull girder strength and stability, is desirable during COW and stripping of the tanks, especially during the final stages of tank discharge. However, the build-up of washing oil needs to be controlled; if the depth of oil at the aft end of the tank exceeds 0.30 meters, the tank needs to be drained before continuing with COW operations.
- Stripping operations should consider the nature of the crude oil:
  - Low viscosity crude oil tanks may be left for a longer period of time to allow for 'run-down'. A re-stripping is recommended.
  - High viscosity/high wax crude oil tanks should be stripped immediately after COW. The final stripping should be undertaken while the tank is still warm.
- Multiple tanks may be washed between offtakes and the washings stored in a designated tank which may then be washed and stripped directly to the offtake tanker subject to any export specification constraints, albeit at a reduced discharge rate.
- Care should be exercised to ensure that any strainers in the export system are not clogged by residues. Periodic cleaning may be required.
- COW branch lines and associated valves should be effectively drained to avoid damages during freezing weather conditions.
- Maintenance of the COW machines is to follow manufacturer's recommendations and also take into account potential extended periods of disuse.

SEDIMENT REMOVAL

- The OCIMF publication 'Cargo Guidelines for F(P)SOs', section 9.6 lists three methods for removal of sediment deposits, which rely on personnel in tanks and as such tanks will need to be purged, water washed and gas-free prior to these operations:
  - Air vacuum eduction system using air-driven vacuum eductor
  - Slurry pumping system using air-driven diaphragm pump
  - Portable winch and sludge buckets or bags
- Prior to commencing any sediment removal operation, it is recommended that representative samples of the sediments are analyzed to determine the composition and any resulting precautions that need to be taken. Toxic vapors may be released when the deposit is disturbed and hence, the atmosphere should be carefully monitored.
- Adequate ventilation and continuous atmosphere monitoring need to be arranged before work starts to mitigate the hazards of any combustible and/or toxic gas release.

PATH FORWARD

LAND BASED INDUSTRY PRACTICES

Currently, there are many practices for cleaning oil tanks that are applied to land industries that have not yet been implemented or tested on a large scale in offshore applications.

ROBOTIC CLEANING

The Multidisciplinary Digital Publishing Institute (MDPI) published a document comparing manual, automated, and robotic cleaning of industrial flat-bottomed oil tanks[2]. Most notable were the findings of the robotic cleaning as it did not require personnel to physically enter the oil tank. The main priority of the robotic cleaning is to remove the crude oil sludge at the bottom of the tank, which is a process currently conducted by onboard personnel.

MARTin ROBOTIC SPECIFICATIONS

The robot utilized in this tank cleaning study was the Mirrico MARTin cleaning robot, which is equipped with video surveillance, a lighting system, a discharge device, components rated for use in hazardous areas, and is hydraulically driven, so the tank does not have to be gas-free during the cleaning process, which can save time and money. Since the MARTin robot is currently used only in land industry oil tanks, the process of separating and cleaning the oil and water is conducted outside of the tank in tractor trailers that are connected to the oil tank.

ROBOTIC CLEANING PROCESS

The MARTin robot excavates the sludge from the bottom of the tank and sends it through an oil sludge draw-off pump, which is then dehydrated and separated to remove sand and colloidal fractions. Once the sludge is separated, it is then sent into the cleaning unit, which has a dynamic gravity separator, used to separate oil and water. The oil is sent off to the customer, while the water gets redistributed to the oil tank for further degradation of the oil sludge. Compared to the automated-mechanical and the manual process, the robotic cleaning proved to be the most effective, as it is the cheapest and safest option. Note that only one robotic method, one manual method, and four automated-mechanical methods were tested in this study. The data shown in the chart below was taken from the MDPI document referenced above[2].

	Robotic	**Automated-Mechanical** (Using jets and machines combined with personnel in the tank)	**Manual** (Using personnel with only manual tools)
Speed	Slightly slower than Automated-Mechanical (6.3 m^3/hr)	Fastest (Avg: 9.2 m^3/hr)	Slowest (3.5 m^3/hr)
Safety	No personnel required	Personnel required, but time in tank varies depending on equipment	Personnel required all the time
	Has equipment rated for hazardous areas	Has equipment rated for hazardous areas	Non-sparking tolls may be required
	Automatic atmospheric monitoring all the time	Automatic atmospheric monitoring all the time	Manual atmospheric monitoring
Environment	Recycles produced waste (95% oil recovery ratio)	Recycles produced waste (Avg: 95.4% oil recovery ratio)	Does not recycle produced waste
Costs	Least Expensive	Varies depending on equipment, can be least or most expensive	Expensive compared to Robotic and some Automated-Mechanical options

As more information and studies develop on robotic cleaning of oil tanks, applications may be applied to FPSO and other offshore vessels, which would increase safety and potentially reduce costs and the time for tank cleaning.

INTELLIGENT TANK CLEANING

In industries such as food processing, intelligent tank cleaning is being implemented for food storage tanks to make tank cleaning more efficient and with increased safety. For example, a fixed, adaptive jet cleaner can be installed at the top of the tank, that has 360° rotation to be able to clean any area of the tank. A contamination sensor can also be placed in the tank, which utilizes fluorescence to detect residual contamination.

Currently, the technology is not developed or tested enough to implement this type of cleaning on something as difficult as crude oil, especially on FPSO vessels. However, in the future, intelligent cleaning could be a viable option to mitigate the need for onboard personnel entering crude oil tanks for cleaning.

POTENTIAL SOLUTIONS FOR NEWBUILDS

Few solutions for limiting the amount of personnel, time and cost of tank cleaning can be implemented into existing FPSO vessels, due to the structural complexity of retrofitting and the amount of downtime required, but there are several design features that can be integrated into a new construction unit to increase the ease of cleaning.

Alternative Designs for Construction
The first option to improve the efficiency of oil tank cleaning is by altering the design of cargo tanks. The current complexity inside single hull cargo tanks makes them very difficult to clean. As stated previously, stiffeners, piping, stringers, and hard-to-reach areas cause tank cleaning to be troublesome and near impossible to automate. Reducing the complexity of the tank design as well as increasing the size of the access openings will allow new remote technologies such as crawlers and UAVs to be utilized for tank cleaning.

One possibility is to use corrugated longitudinal and transverse bulkheads between cargo tanks in the newbuilds. Corrugated bulkheads have many advantages over flat stiffened bulkheads that are in almost all existing FPSO vessels. Corrugated bulkheads offer easier maintenance, less weight for the same structural strength, less corrosion, and most importantly, reduced shadow areas. Corrugated bulkheads eliminate the need for stiffeners on flat bulkheads, which can create shadow areas not reachable by the COW nozzles. Any horizontal corrugations, however, must have an angle less than or equal to 45° with respect to the vertical plane to ensure that the jets can have sufficient impact on the surface.

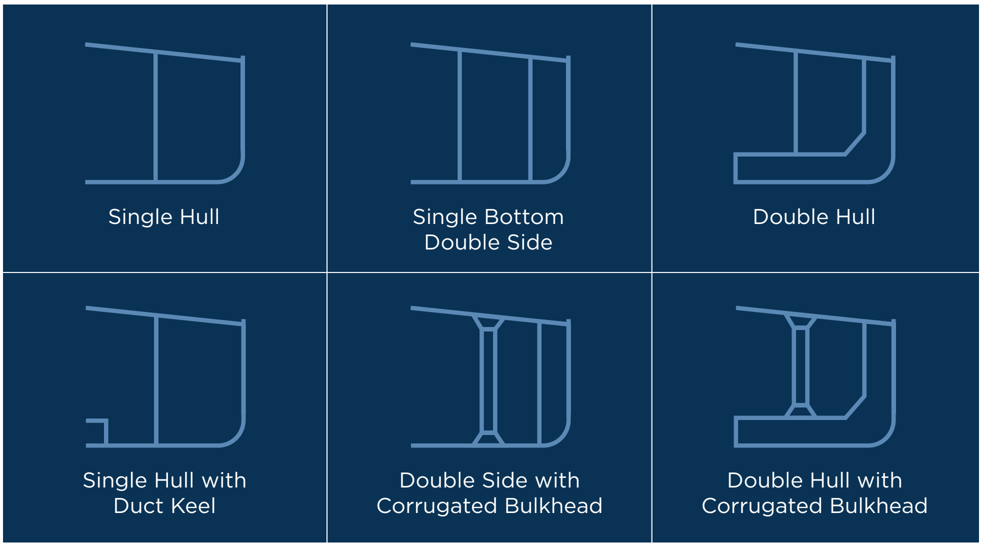
Another change from the current tank design is to use L-shaped connections instead of T-connections for stiffeners on longitudinal bulkhead and side shell. T-connections cover a substantial amount of surface area and create shadow areas that are unable to be cleaned from COW nozzles. In addition, T-connections retain more sludge on top of a horizontal stiffener, and an L-shape allows for the sludge to flow off easier.

Implementing a double hull for FPSO vessels could provide greater ease in cleaning the cargo tanks. Adopting a double hull would decrease the number of obstructions, such as piping and stiffeners, in the oil tank, resulting in a simpler tank layout for cleaning. The removal of piping and stiffeners would decrease shadow areas, making the COW nozzles more effective. Additionally, this simpler cargo tank layout allows for more opportunities for robotic cleaning of the cargo tanks. One side effect of double hull units is the increase in area of ballast or void tanks in locations remote from the tank entry. The amount of ballast or void area to coat and examine increases significantly when compared to a unit with only double sides. Examples of typical hull constructions are shown in the figures below.

A smaller change to the single hull design would be to include a duct keel in the center of the unit, which would allow the piping obstructions to be mostly removed from the cargo tank. This could have the added benefit of allowing for access to and maintenance of valves. This design was used successfully in VLCCs designed in the early 1970s.

Currently, the access openings to tanks are too small to fit larger UAVs and crawlers for robotic cleanings. In FPSO newbuilds, having an increased quantity and size of access holes would permit many more remote inspection vehicles (RIV) access inside the tank. Access to the hatches, and the ability to use the cranes or portable lifting frames to allow the use of larger and heavier equipment should also be considered during the design stages. The use of remote cleaning using RIVs could potentially remove the need for human entry into the tank, which would increase safety and potentially save lives during tank cleaning.

Most of the cleaning effort expended is typically in the removal of sludge in cargo tanks, but scale and mud accumulation can be problematic in narrow side tanks and in double bottom tanks. Tanks with no coating or failed coatings may require mechanical cleaning to dislodge adhered scale and loose scale from the bottom of the space. Tanks with intact coatings may have mud, but most FPSOs are in deeper waters, which minimizes the amount of mud that is added to the tank during ballasting. Cleaning equipment proven effective in cargo spaces may work satisfactorily in these spaces also if the access to the space is large enough to accommodate the equipment. Double bottom tanks that require cleaning would need accesses through longitudinal bulkheads and transverse frames to allow remote cleaning equipment.

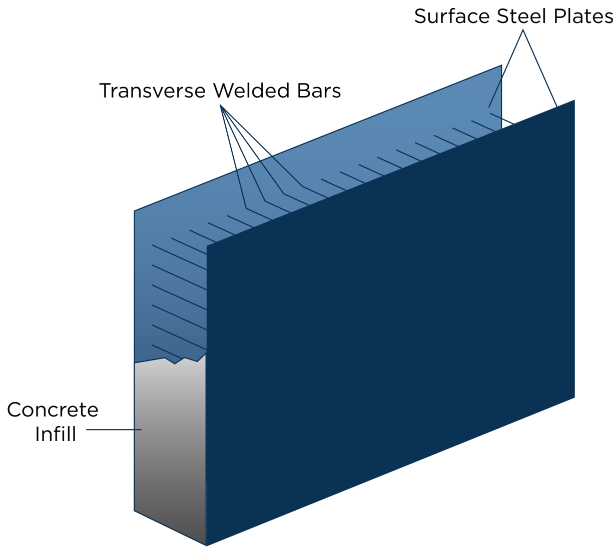


Automated cleaning methods typically require several twenty-foot containers worth of support equipment. For their use, adequate room on the deck for the equipment is required, or the support equipment will need to be built into the unit with outlets for power, hydraulics, piping and communications at appropriate locations.

If remote inspection devices are developed that can operate in an inert atmosphere, provision for entry of the unit into the tank without exposing the tank to air may be required. Current optical means of examination are reported to lose effectiveness in an inert atmosphere.

Alternative Materials

The use of some alternative materials for construction of FPSO oil tanks could help in reducing the amount of oil residue and corrosion. Currently, FPSO tanks are constructed with steel and coated, which is inexpensive and bears the required strength, but it is prone to corrosion and fatigue stresses over time. Some of these possible alternative materials include the use of concrete laminated with steel, steel laminated with epoxy, high strength plastics, and other materials.



Concrete laminated with steel construction involves using steel plates set a certain distance apart from each other in the same orientation with the gap between filled with concrete. The internal gap would likely require some reinforcement like stiffeners or connections from plate to plate, but this would allow for the internal tank space to be free of structural components and therefore easier to clean and inspect. See the diagram on the right for an example of steel construction laminated with concrete.

Steel construction laminated with epoxy or high strength fiber-reinforced plastics both could be beneficial when developing new methods of oil tank construction. The benefits of using these types of materials come in the form of reduced or non-existent corrosion of steel within the tanks. This makes the tank easier to clean, reduces the amount of scale build up, and reduces costs in recoating and the repair of steel components over the life of a vessel. High strength and high temperature coatings that have been developed specifically for offshore pipelines, could potentially be applied to cargo tanks. It is important to note that this or similar technology requires more extensive research and development to determine viability.

All of these alternative materials or combinations of materials need further study beyond the scope of this document. They are briefly discussed here is to shed some light on their existence and that traditional steel construction may not be the only option moving forward.

Adjustment, Increase, and Location of COW Nozzles

With current methods, COW nozzles are required to be able to cover at least 90 percent of the horizontal areas and 85 percent of the vertical areas of the tank surface, but horizontal stiffeners, piping and other structural obstructions create shadow areas not able to be accessed by the COW machine crude oil spray patterns. Changes in the COW nozzle system could allow for a more efficient cleaning by having shadow areas sprayed with crude oil as well. COW nozzles are typically only installed on the upper deck of the oil tank.

Increase in the number of COW nozzles and possible implementation of COW nozzles near the floor of the tank could assist in cleaning the shadow areas of the tank, but it would require a redesign of the piping of the COW system. Single nozzles are typically programmed for rotation speed, rotation degree, washing time, flow rate and quality of wash. As an alternative to programmable machines, there are non-programmable machines that wash all available areas, preventing crew from only washing the bottom of the tank (thus allowing buildup on vertical and other surfaces away from the bottom of the tank). Current chemical tanker standards, from MARPOL Annex II, require hot water washing to have a minimum temperature of 140 °F or 60°C and have sufficient pressure and flow rate to clean the entire cargo tank. Adjustments to these programmable settings could allow for better results from COW and result in less hassle in clean-up post-COW. The system can be designed to more stringent standards than the minimum MARPOL requirement. ABS has developed the notation ECTC, described in the ABS *Guide for Enhanced Cargo Tank Cleaning* which requires an increase of COW coverage to 96 percent and a minimum temperature increase to 185 °F or 85 °C.

Chemical Cleaning
Chemicals and/or chemical solutions are not widely used in the cleaning of crude oil tanks onboard vessels due to cost to supply to the unit, cost of disposal, possible negative environmental effects and the challenges associated with removing the chemicals from the cleaning system.

"Deepwell" Pumps
Another option for making tank cleaning more efficient is by altering the piping system by using "deepwell" pumps. Currently a typical cargo system used for cargo operations utilizes a pump room that has 3 pumps which are connected to tanks through cargo piping routed through the bottom of the tank. The use of hydraulically driven submersible pumps would eliminate the need of having a pump room with accompanying safety benefits, and also allow the removal of horizontal cargo piping, valves and expansion joints and associated supports from within the bottom of the cargo tanks and transition to fewer vertical pipes leading to the deck above where the cargo piping would alternatively be located.

Hydraulically-driven submersible pumps are already found on most chemical and small product tankers and have also been installed on most new FPSOs. The horizontal hydraulic piping for the pump is located on the deck of the vessel, so no additional obstructions are added into the tank. Electrically driven pumps on deck with shafting running down to the pump are generally used for vessels with less than 25m hull depth, and some operators have reported issues with bearings when used at greater depths. Also, if heating is required, deck mounted cargo heaters can remove the need for in-tank heating coils, allowing for fewer obstructions within the tank. These submersible pumps have proven to have excellent pumping capability and final stripping efficiency as well as a more flexible cargo segregation, which would significantly help reduce the time and effort of sludge cleaning. The Oil Companies International Marine Forum has published the C*argo Guidelines for F(P)SOs*, which goes into detail about the benefits and challenges for different types of pumping systems.

PUBLICATIONS

INTERNATIONAL STANDARDS

- International Chamber of Shipping – International Safety Guide for Oil Tankers and Terminals
- MARPOL Annex I
- MARPOL Annex II
- IMO XI/Res.446, IMO XII/Res.497, IMO 21/Res.897
- OCIMF — Cargo Guidelines for F(P)SOs (1st Edition)
- IMO — Crude Oil Washing Systems (COW) (2000 Edition)
- OCIMF — Guidelines on the marine assessment of F(P)SOs
- Energy Institute — HM 40 Guidelines for the crude oil washing of ships' tanks and the heating of crude oil being transported by sea (3rd edition)

ABS RULES AND GUIDES

- ABS *Rules for Building and Classing Marine Vessels 2021 – Part 5C*
- ABS *Guide for Enhanced Cargo Tank Cleaning*

REFERENCES

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2. Chrysalidis, A.; Kyzas, G.Z. Applied Cleaning Methods of Oil Residues from Industrial Tanks. Processes 2020, 8, 569. https://doi.org/10.3390/pr8050569

TANK ARRANGEMENTS

OVERVIEW

OBJECTIVE

The objective is to design a unit that will operate safely with optimal production time and minimal interruption to production from tank examination and repair activities.

The offshore production industry faces challenges to design FPSO units that can continuously process, store and export produced oil while allowing for hull inspection, repair and related operations simultaneously. The tanks in the hull of an FPSO may need to store the following liquids with minimal negative impact on production activities:

- Produced oil
- Off-spec oil for return to process units
- Produced water pending disposal
- Slops water for decanting
- Tank washing liquids and residue
- Flow assurance fluids pending disposal
- Well unloading chemicals
- Chemicals for protection from hydrates during shutdowns
- Other liquids that may be required for specific sites or unit designs

In addition to those functions, some units have weirs in tanks to take the place of late-stage separation of oil, water and salts. This separation was traditionally done using electrostatic treaters or third stage separators but has been shown effective in cargo tanks using purpose designed patented separation methods.

To accomplish these goals, the designs for these tanks will be required to have some resistance to corrosion, with the degree of resistance dependent primarily on the liquid composition and the time the corrosive liquids will be present in the tank.

Currently, converted units typically use the tanker slop tanks as installed, and may separate one cargo tank into two tanks to form an off-spec oil tank and a produced water tank. Depending on the original design, slop tanks may share a common bulkhead. New construction units may have specialized tanks installed and layouts that are not typical for a tanker. All of these designs may have challenges to meet the demanding requirements placed on them during operation.

CHALLENGES

There are many items that need to be considered when identifying the needs of the unit, some of which are listed below:

Production Needs
The system must accommodate the needs of the topsides production plan throughout the life of the wells, from initial connection and flushing, all volumes of production, flow assurance activities, and end of life production along with water injection or other well stimulation activities.

MARPOL Annex I
MARPOL Annex I Regulation 39, Unified Interpretation 67, identifies that waste streams generated as part of the production activities are treated separately from marine waste streams. These documents also identify that seawater introduced into cargo tanks for washing would fall under MARPOL Annex I requirements. If seawater is used for tank washing, the contents of the slop tanks will require disposal in accordance with MARPOL Annex I instead of being disposed of as produced water which is regulated by the coastal authority and not MARPOL. This means that a separate means of disposal may be required for slop tanks and other tanks retaining produced water.

The MARPOL Annex I Appendix 5 and depicts the requirements of MARPOL Annex I Chapter 7 Regulation 39 and shows the activities covered under MARPOL Annex I and production activities controlled by the coastal authority. The five categories of waste streams that Regulation 39 identifies are:

1. Machinery space drainage
2. Offshore processing drainage
3. Production water discharge

4. Displacement water discharge
5. Contaminated seawater from operational purposes such as:
    a. Produced oil tank cleaning water
    b. Produced oil tank hydraulic testing water
    c. Water from ballasting of produced oil tank to carry out inspection by rafting

The only categories that MARPOL Annex I applies to are the Machinery space drainage (oily bilge water) and seawater introduced into oil storage tanks.

Out of Service Requirements
One key challenge is the requirement to take a tank out of service for examination and conduct any necessary repairs with minimal to no impact on production and tanker offload schedules. Tank out of service time includes time for crude oil washing, water washing, purging, gas freeing, confined space entry (CSE) isolations, manual cleaning as required, inspections, applicable repairs, testing then tank de-isolation and re-inerting to place back in service. Following the traditional floating production installation class cycle, this requires each tank to be examined at least once every five years. This five-year schedule may change if the unit is on a risk-based inspection scheme, which may require examinations on a more frequent or less frequent basis. At least one flag has invoked MEPC.311(73) to some extent. MEPC.311(73) as written requires FPSOs to follow almost all enhanced survey program (ESP) requirements. ESP requires all cargo tanks and ballast tanks to be examined twice in a five-year period for vessels over 10 years of age. If a flag requires this, the unit may need to be designed to allow for multiple tanks to be out of service simultaneously to meet the required examination schedule. Currently, most flags accept the class rules and examination schedules as meeting the intent of MEPC.311(73) without the need to conduct the twice in a five-year period examination.

Coastal State Regulations
Coastal state regulations for the quality of produced water discharged may differ from the requirements for machinery spaces required by MARPOL Annex I and may change over time. Treatment skids may be required late in the life of a field to treat increasing volumes of produced water or to accommodate stricter regulations. During transitional periods, large quantities of produced water may need to be stored on board the unit for long periods of time until it can be treated. Coastal state regulations may also conflict with flag state regulations for disposal of slops water and allowable oil concentrations for overboard discharge.

Sloshing
Units with spread moorings or which operate in rough water may experience sloshing and rolling during operation that can make separation of oil and water in slop tanks or other gravity separation tanks more difficult.

Produced Water Composition
Produced water may contain any number of a variety of characteristics or substances that induce or encourage corrosion, including high temperatures, low pH, H2S, CO2, and salts. Produced water may also be denser than seawater, increasing loads on surrounding structures. The design needs to account for any issues in the tanks that may be caused by these properties, along with corrosion in connected piping systems. This may require coatings and redundancy to provide continuous operation and production.

INDUSTRY BEST PRACTICES

POSSIBLE TANK CONFIGURATIONS

Operators are currently including two to five tanks in their designs for use other than cargo tanks, depending on the expected amount of water expected or whether the field will have water injection, which can increase the amount of water significantly as the wells play out. FPSOs based on tanker philosophies may have slop capacity from 1.5 to 3 percent of the total cargo capacity with only two tanks, while other units may include larger slop tanks and/or additional tanks that can serve as slop tanks. Typically, these tanks are created from dividing a full-sized cargo tank or designing the unit with several relatively small tanks that can be used for multiple purposes.

Many of the designs have the slops in locations where they are not adjacent to each other and may have the other tanks designated for water also separated by a tank or cofferdam. This allows for removal of one tank from service and the ability to conduct hot work on any bulkhead without impacting the ability of the other tanks to continue to operate.

To prevent bottlenecks, ABS is also implementing a requirement to include a tank to serve as an additional slop tank or take the place of any tank other than a cargo tank that is necessary to continue production in 2022. Tanks in current designs may have one or more of the following specialty designations:

- Slop tank
- Off-spec produced oil tank
- Produced water tank
- Flow assurance tank
- Tanks designated for use with chemicals designed to prevent hydrate formation

To promote normal operation of the production system and allow offloads to continue while tanks are being examined, all specialty tanks such as the ones listed above should be arranged and piped to be interchangeable whenever possible when they are fitted, subject to restrictions related to fiscal metering and environmental regulations for managing oily water mixes.

CORROSION CONTROL

Produced water is generated from wells and is typically a corrosive mixture of salt water that may have a low pH or contain H2S and other components that encourage corrosion. It may require storage in the hull for separation or pending disposal. Corrosion from produced water happens in the hull when produced water is stored in tanks without adequate corrosion protection in place. Other liquids, such as brine or flow assurance fluids may have similar effects, and for the purposes of this discussion are referred to simply as “produced water”.

The first step to control corrosion is to designate adequately protected areas for produced water.
The next step is tracking the quantity and locations where the produced water is kept.

Because produced water frequently encourages microbial-induced corrosion, the length of time produced water is stored onboard is also a key factor.

There are several strategies that have proven to be helpful in controlling this corrosion, and the strategy used will depend on the conditions in the field. Some of the strategies that have been used are:

- Coatings
- Anodes
- Minimizing exposure time
- Oil displacement
- Chemical treatment

Tanks that will regularly receive produced water, such as off-spec oil tanks, produced water tanks, and slop tanks are normally fully coated in new or converted units with anodes fitted to retard corrosion in way of any localized coating breakdown.

Most operators have elected to coat the top and bottoms of all cargo tanks similar to that required for trading tankers by SOLAS Chapter II-1 Part A-1 Regulation 3-11. The bottom coating is to protect against any water that drops out of suspension while being transported or stored prior to offload, and the coating at the top is to protect against the corrosive effects of inert gas. Some operators have increased the extent of coatings at the top of the tank to include all structure and plating above the normal liquid line and all surfaces of the bottom area, up to 2 m above the bottom.

Using the above methods may allow for limited amounts of produced water, or larger amounts for limited times to be stored in cargo tanks without corrosion issues. The amounts, locations, and durations should be tracked to prioritize and determine the extent of examination of the plating and internal structures of the tanks.

Because some water is expected to drop out of suspension, installation of anodes at the bottom of any tank expected to hold produced water is recommended, especially for units that may have water sitting on the bottom for more than three months. Small paint defects have caused accelerated corrosion when exposed to produced water, resulting in localized corrosion in excess of 2 mm per year. This may be higher if adjacent to stainless steel submerged cargo pumps or heating coils. Operators should carefully consider the corrosion risks in their RBI program and increase corrosion inspection frequency in tanks which have water in them. Further, it is important that the operator tracks the storage, level and transfer of produced water in the tanks, especially when not fully coated. The operator should maintain a Produced Water Management Plan and Record on-board to:

- Ensure consistency of operations
- Avoid water being placed haphazardly into unprotected tanks or tanks which already have corrosion issues
- Feed into the RBI program

Corrosion should be expected on all uncoated surfaces, with the extent dependent on the time the unit is in operation and the conditions to which the steel is exposed. Class Societies specify corrosion requirements, and many operators add an additional margin based on experience to end up with 1.5 to 4.0 mm for 25 years of operation.

At least one tanker operator has reported a reduction in the corrosive effects from inert gas (which can form sulfuric and carbolic acids) by installing a secondary scrubber in series with the normally fitted scrubber. Taller scrubber towers have also been fitted by operators, which are reported to reduce the amount of acids, while keeping the moisture content lower than two scrubbers, so long as two mist removal stages are used. These have been reported to reduce the amount of corrosion experienced in the gas space above the cargo. This type of corrosion may also be retarded by using a hydrocarbon blanketing system with gas from the wells keeping the tanks in a low oxygen environment, so long as the gas produced does not contain corrosive substances, such as H2S.

PATH FORWARD

Fluid Simulation at Design Stage:
One possibility in the design of an efficient system to process the fluids could be a process simulation. This simulation should include incoming process fluids and the capabilities of the unit to dispose of waste fluids. The unit could be required to conduct all of these activities while in operation, so the more realistic the simulation can be made, the more useful the final result will be. The results of the simulation will provide insight into the results that the listed conditions may incur. These should be considered in the design, with the understanding that the scenarios may be considered to be unlikely enough that the design could remain unchanged with the understanding that mitigations will be required if those conditions are encountered during operation, such as reduced loading levels, more frequent offtakes, or process shut down. The simulation should consider the following items and stages of operation:

1. Calculate incoming fluids and tankage levels during operational life:
    - Include expected produced fluids for the life of the wells in the field
    - Water injection will increase produced water content later in life
    - Additional wells brought on-line
    - Tanker sizing for offloading
    - Ports for likely offloading, which sets tanker schedules
    - Consider fluids generated from:
        - Slugs and process upsets
        - Flow assurance activities
2. Identify “worst-case scenarios” for process tankage needs, considering at least:
    - Off-spec oil
    - Produced water
    - Slops
    - Flow assurance
3. Verify suitability of tankage for expected activities in the following conditions, considering the effects likely scenarios would have on production:
    - Simulate removal of each tank from service for repair/inspection while producing at worst-case scenario levels
        - Off-spec tanks
        - Slop tanks
        - Cargo tanks
        - Calculate available offtake with any one tank out-of-service at worst-case scenarios

- Remove similar tanks from service if they are adjacent- as would happen if the common bulkhead required repair
  - Off-spec tanks
  - Slop tanks
- Tanks that collect residue quickly (slops) may need longer out of service periods for cleaning
- Normally occurring radioactive material (NORM) may slow down the inspection process, especially in slop tanks
- Repairs of bulkheads or at tank intersections might remove up to four tanks from service simultaneously
  - Note that this is in excess of class requirements and may involve reduced loading in some tanks.
- An in-service inspection plan (ISIP) or risk-based inspection (RBI) plan may require frequent examination of some tanks based on their design or condition, requiring multiple tanks to be out of service simultaneously to meet scheduled inspection times
- Tanks on older units will require longer times to examine and repair
- Single bottom tanks and tanks with more internal structure will require more time to clean and inspect
- Calculate hull girder bending and shear strengths in each expected condition so as to always remain within allowable limits

Notes:

- The ISIP or RBI plan should be consulted for frequency of examination, and feedback from the simulation may be used to assist in setting the survey scheduling.
- ISIP and RBI examination schedule should stagger survey schedule of similar tanks so that a delay of one tank will not affect others (e.g. slop tanks examined two years apart instead of sequentially)
- To prevent long out-of-service periods that could affect production, examination schedule should consider more frequent removal of sediments in problem tanks
- Cargo and offload manuals for discharge operations and conditions should be designed based on the results of the simulation

PUBLICATIONS

INTERNATIONAL STANDARDS

- Resolution MSC.291(87) Amendments to Chapter II-1 Part A-1 Regulation 3-11
- Resolution MSC.288(87) Performance Standards for Protective Coatings for Cargo Oil Tanks of Crude Oil Tankers
- MARPOL Annex I
- Resolution MEPC.311(73) 2018 Guidelines for the Application of MARPOL Annex I Requirements to Floating Production, Storage and Offloading Facilities (FPSOs) and Floating Storage Units (FSUs)

ABS RULES AND GUIDES

- ABS *Rules for Building and Classing Floating Production Installations*
- ABS *Guide for Performance Standards for Corrosion Protection*
- ABS *Guidance Notes on Cathodic Protection of Ships*
- ABS *Guidance Notes on Maintenance and Repair of Protective Coatings*

RISK-BASED INSPECTION OF HULL STRUCTURES

OVERVIEW

OBJECTIVE

Traditional inspection regimes use inspections on a calendar basis to verify the integrity of an asset. When this is applied to structural elements, the calendar-based inspection regime is typically supported by a general vessel type-specific scope, usually guided by class rules, which requires opening tanks, spaces and compartments on regular intervals, regardless of the criticality or level of risk involving that part of the asset.

Classification requirements for surveys also follow the same process, with calendar-based surveys following a prescriptive vessel type and age-specific scope to cover the entire asset over a period of five years.

Offshore assets such as FPSOs and FSOs (or F(P)SO) also have degradation mechanisms and load patterns that are different from marine vessels and have many customized structural features that are unique to that specific unit. A key difference in the operation of such vessels being that contrary to regular drydocking intervals of every 2.5 years, the very basis of the ship inspection and survey requirements, F(P)SOs often remain on station for their entire service life. Being stationary, F(P)SOs are subject to a more uniform parcel offloading pattern and site-specific environmental conditions that make the structural load aspects more predictable. This creates the opportunity to consider a different inspection/survey regime from sailing ships.

The service experience with floating systems worldwide, the effects of various degradation mechanisms on floating asset structures are now well known, and often warrant a more thorough asset-specific customization of inspection and survey requirements. These include:

- Incorporation of purpose-built design features, requiring asset-specific knowledge
- Access and ease of inspection and maintenance in-situ, including simultaneous operations (SIMOPS), without drydocking
- Difficulty and need for unique and temporary repairs to facilitate logistics offshore
- Plan for life extension(s)

Risk-based inspection (RBI) provides the alternative means to develop an asset-specific in-service inspection plan (ISIP) for the hull vs. class rule-based or calendar-based inspection regimes. Most class societies also provide a mechanism to approve such RBI plans as the approved means to maintain class as well as dovetail the class survey requirements to be performed with the RBI plan. The goal of RBI is the same as the conventional rule-based approach, i.e., the prevention of inspection-preventable incidents that impair the safety and reliability of the asset. However, RBI achieves this goal by using risk assessment and risk management processes to develop and manage forward-looking inspection plans that direct inspections to the areas of highest risk as well as manage the plan execution using a risk-informed process. RBI is tailored to asset specific designs, and also allows for the unique structural and site-specific features of the F(P)SO to be accounted for rather than the prescriptive requirements of the rules. An added benefit of this approach is to improve operator safety by minimizing personnel exposure when performing inspections (i.e., safety risks with confined space entry of cargo tanks). Another benefit is that RBI is a dynamic process, where the results of inspections can inform and update the plan and drive the frequency and depth of future inspections, allowing for a more dynamic ISIP.

This paper provides best practices for the effective development and implementation of an RBI program on F(P)SOs in accordance with classification and international standards.

OPERATIONAL CHALLENGES

F(P)SO integrity management is complex. In addition to the hazards associated with oil storage in the hull tanks, there are risks due to the hazards inherent to oil and gas production systems and the risers connected to the wells, essentially a mixture of simultaneous operations that bring their own unique challenges. These aspects also bring additional challenges to asset integrity management tasks.

Focusing on the structural integrity aspects, the need for inspections and repairs while the F(P)SO is operating presents challenges to the execution of the integrity management plan of the facility. The challenges and best practices for conducting repairs while the unit remains in operation are presented in the section “Conducting Repairs While Operating” within this document.

Carrying out inspections on board an F(P)SO with concurrent production operations is a major undertaking and requires detailed integrated planning, supporting good coordination of activities. Performing these inspections on a calendar-based execution schedule with a fixed scope may adversely impact the production rates of the unit without an increase in asset safety or the consideration of the various risk unique to the asset. The pre-defined and ship practice basis of the scope defined in the rules may not consider asset specific issues such as the structural areas that present higher level of criticality or the potential consequences in case of a failure.

Confined space entry for any type of activities including tank inspection and repairs is inherently hazardous, and there is a risk of injury and potential for fatality if risks are not managed accordingly. F(P)SO operators are faced with additional challenges to execute general visual tank inspections, or overall close-up structural inspections, such as:

- Confined space entry of storage tank(s) concurrent with production flow in other storage tanks, noting that most challenges are similar to the ones in trading tankers:
  - Entering a tank requires complete cleaning and gas-freeing of the compartment
  - Provision of ventilation, lighting, access, etc.
  - Certification that the tank atmosphere is safe for entry, especially if residues remain in the tank
  - A high temperature atmosphere in the tank, depending on geographical location
  - Equipment and consumable handling in situ are more challenging for the F(P)SO
- Tank isolation
  - Storage tank(s) to be inspected need to be positively isolated per operational standards and taken out of service
  - Tank systems positive isolation can be a challenge, making it difficult for storage tanks and related piping systems to meet positive isolation standards. In particular, this challenge is more noticeable with F(P)SOs converted from conventional tankers with pump rooms and bottom piping, as compared to newer F(P)SOs fitted with submersible pumps and no in-tank lines
  - Safe de-isolation of tanks and return to service (similar situation faced in a trading tanker)
- Operations impact:
  - For void tanks/spaces with dehumidification opening the tank for inspection reintroduces a more corrosive environment
  - Simultaneous operations (SIMOPS) aspects
- Personnel aspects:
  - Tank cleaning operations (if required) may expose personnel to safety hazards such as normally occurring radioactive materials (NORM), mercury, etc.
  - People on board (POB) constraints while carrying out inspections in order to accommodate additional personnel such as rope access teams, scaffolders, inspection technicians, painters, tank cleaners, class surveyor, rescue personnel, etc.

Other drivers to minimize tank entry include structural aspects, since emptying a tank can induce higher hull stresses and low cycle fatigue effects that may increase the likelihood of structural damage over the life of the asset.

Additional challenges are also faced by the owner/operator of the facility and may involve financial aspects (inspection budget, scheduling, logistical aspects, etc., which are not part of the discussions herein.

WHAT IS RBI?

Risk-based inspection (RBI) utilizes a risk assessment and management process to develop and manage a forward-looking inspection plan that directs inspections towards the areas of highest risk. It focuses on failure modes initiated by material deterioration or degradation mechanisms where risk can be effectively addressed through inspection of equipment and structures.

By optimizing the inspection regime using risk-based techniques, opportunities may also be identified to minimize not only asset risks but also, as mentioned above, the safety risks to personnel performing inspections. RBI is a proven dynamic asset integrity management method that uses risk techniques to prioritize inspection activities, identify and understand risk drivers, and as a consequence, develop and implement effective risk mitigation strategies. RBI specifies which components to inspect ("where"), identifies the degradation mechanism and the components that are affected by these mechanisms ("what"), the appropriate inspection method for each particular scope ("how"), and then defines the frequency of the inspections ("when").:

- Where to inspect: RBI Plan has the benefit to make both the operator and surveyor more aware of asset-specific critical locations
- How to inspect: RBI plan requires formal data collection from visual and NDE as needed, that allows for a continual data feed to validate or update the RBI plan
- When to inspect: Given the site and asset specific knowledge of design features and degradation mechanisms, also considering produced fluids and the Management of Change (MOC) as the field ages due to compositional changes (composition, temperature, water content, etc.), drop in production/low usage, which can impact degradation rates or mechanisms within the tanks and also allow potential customization of Class requirements for tank entry, gauging frequency, with Port and Flag State approval.

When incorporated into the overall structural integrity management program for offshore structures, RBI is an effective technique that contributes to the overall lifecycle management of the asset and is aligned with industry standards such as API RP 2SIM for fixed offshore structures, API RP 2FSIM for floating systems, API RP 2MIM for mooring systems, and API RP 2RIM for dynamic risers.

ABS provides requirements for RBI in the ABS *Guide for Risk-Based Inspection for Floating Offshore Installations*. This guide provides for an approval mechanism for the plan as well as guidance on how plan execution shall be conducted with Class involvement and consideration of all prescriptive and statutory survey requirements for the asset.

RBI provides the opportunity to understand the asset's current state and facilitate a decision-making process when prioritizing the inspection efforts and resources without compromising and potentially enhancing the safety of the asset.

RBI is a dynamic program and requires continuous updates based on the acquired knowledge of the asset gained during and from the inspections. This cumulative information drives the re-evaluation of the risks, criticality, and consequences, providing the necessary basis for an annual reassessment and updating of the plan. RBI plan validation can also leverage information acquired through monitoring processes and systems, such as corrosion coupons, process fluids composition sampling, and condition data trends from gauging reports that may include corrosion rates and other information.

Another recent trend is the utilization of data that is tracked within digital realms and covers aspects of a digital twin used to continually capture and understand the load history and condition of the asset in its current state, in order to maintain the RBI plan in a continually evergreen and validated state. These techniques may include such techniques as monitoring of in situ loads and metocean data, the use of sensors for response and various model calibrations to validate fatigue damage accumulation, and also condition models and databases to store condition data and trend degradation.

PHASES OF RBI IMPLEMENTATION

RBI PLAN DEVELOPMENT

The RBI program requires the development of a plan submitted to class for review and approval. The effectiveness of an RBI program depends directly on the level of effort involved in the development of the plan. A thorough knowledge of the structure and its components and degradation mechanisms is very important for an effective program.

Best Practice: Effective RBI is a holistic process that requires looking at each structural component as part of a dynamic system.

Best Practice: Conditions that drive risk are not always intuitive. RBI often helps uncover issues that are not always evident for all involved in the operations or asset integrity management processes.

Example: In an instance where buckling has been identified as the primary/likely failure mechanism, a fatigue crack may not be the highest risk element of that structural element. Rather, there may be conditions generating the increased fatigue loads that require additional attention. As such, a modified loading condition may be required in order to address the premature failure of the element.

Example: Significant corrosion is always a concern in a compartment. However, investigating the reasons for the corrosion may detect operational conditions that is causing it: produced water in the tank, failure of dehumidification system, defective vent pipe allowing seawater entrance in a void space, production compositional changes (composition, temperature, water content, etc.), drop in production/low usage, etc.

Best Practice: Draft RBI plan to be developed during detailed engineering phase as a project deliverable to operations. Later the plan may be further developed considering operational aspects. For an existing asset, the plan is to be developed considering as a minimum the inspection history, current conditions of the asset, and the original design conditions.

The development of the plan involves several activities, which are listed below along with best practices to optimize the results:

- Data Gathering Phase

  Quality data is at the core of the RBI program. There are a large number of records required to properly develop the plan, but at the same time there are large amounts of data needing to be filtered as it does not impact or contribute to the effort.

  Best practice: Utilization of all available design information including: design basis and criteria, strength, buckling or fatigue analysis results, incorporated unique asset structural features, areas modified from tanker to FPSO use, materials of construction for existing hull or repaired/retrofitted areas, can directly impact the quality of the RBI program. Such data is the most important feedstock to the RBI plan development.

  Best practice: Although this is a practice that should be standard to any type of facility, whether in RBI or not, maintaining historical inspection records, repair and modification records, and operational history (such as loading/offloading pattern, type of fluids stored in tanks, environmental data, etc.) is particularly important when an RBI program is implemented. Incomplete vetting of hulls used in conversions often results in F(P)SO issues or anomalies that are discovered in situ as an F(P)SO, but are the result of old damage during the tanker phase of its history. It is worth the effort to spend the time up from to document the hull's baseline condition as the starting point for RBI plan development and execution. This will allow for such damage-prone details or systemic historical damage to be repaired while in the yard and also for those locations to be incorporated into the RBI plan as a good understanding of the RBI plan starting point.

- Component Grouping Phase

  This step delineates the components within the asset hierarchy into manageable logical groupings, or "inspectable units" (i.e. some aspect of the hull that if it is planned to be inspected, given the preparation and planning, you might as well cover the whole of the unit, i.e. a tank) with an understanding of the applicable degradation mechanisms driving the scope of inspection within that unit. Offshore hull structures, mooring systems, marine systems, riser systems, and topsides modules consist of many components, and each has a role/function in the overall integrity of the asset.

Best practice: Understanding the complex interactions and dependencies of these elements will determine the efficacy of the program. This statement really boils down to a question of damage mechanisms and the correlation for those mechanisms across a grouping of structural components, if that correlation exists at all. In other words, what are the prevalent damage mechanisms, the best approach to inspect for them, and lastly what to do when anomalies are discovered for those damage mechanisms. As an example, for fatigue prone locations, what are the most likely locations to inspect for fatigue damage in a compartment within a grouping of connections whose damage is driven by the same dominant loads, and then should damage be found how does one expand and escalate the inspection scope for that grouping. Those answers are needed as part of plan development, so they are ready for plan execution.

- Risk Assessment and Risk-Based prioritization

The risk assessment for the prioritization step in the development of an RBI plan is limited to the scenarios resulting from deterioration mechanisms of the components within the scope of the analysis, and which can be detected by inspection, but also further informed by the asset unique structural features.

Best Practice: Define inspectable units, delineating asset hierarchy into manageable logical groupings

- Groups to be large enough for significant consequences upon failure
- Groups to be small enough to have similar load and degradation mechanisms

Best Practice: Structured worksheets summarizing the following for each of the inspectable units is a great aid to facilitating the RBI study processes:

- Current condition (for a conversion), or as-built configuration (for a new-build), unique design features, intended service and environmental exposure, damage mechanisms present, corrosion protection systems, if implemented.
- Stress levels, fatigue lives, bucking prone areas (ranked in some way) in order to define critical areas for inspection and the inspection type to be conducted in tandem or to augment class survey scope requirements. This information supports either a qualitative RBI planning session as scope input or as a qualitative lead into a more detailed quantitative study where structural reliability principles may be invoked to determine optimal inspection frequency, based on the inspectable unit's established risk tolerance for threshold limit crossing by one or more components in each group) as part of RBI plan development.

Best Practice: Selection of the decision-making team for the prioritization is very important. A cross-functional team with engineering, operations, maintenance, inspection and risk assessment with related experience and proper delegation of authority for decision making is highly recommended. Marine operations experience is also recommended in order to keep a balanced team and focus on the hull and marine aspects of the RBI program in concert with the myriad of Class objective survey requirements (covers, hatch coamings, manholes, scuttles, sealing arrangements, vents and relief valves, COW and IG systems, guardrails, walkways, etc.) that are not driven by RBI study scope but may in fact drive the overall scope and schedule of the inspectable unit.

- Definition of Inspection Frequency and Methodology

Once the areas are identified along with their risk profile, the next step is to define the inspection frequency and methodology to be used on each of the critical inspection points. RBI uses the same inspection techniques as traditional methods, but scope, frequency and prioritization are driven by the risk-based approach and customized to the asset's structural features. The ABS Guide for Risk Based Inspection for Floating Offshore Installations present a table with different degradation mechanism and the recommended inspection methods to be applied.

One key factor in defining inspection frequency is estimating the likelihood of an undesirable condition occurring based on the component's current condition and degradation rate. As such, each inspectable component should have its own inspection interval defined based on the component reaching a damage condition (rather than failure), but realizing that the worst cases within an inspectable unit may drive the overall inspection frequency of that unit (i.e., the tank entry and prep). For plan management, these decisions are part of managing the plan with time and are directly dependent on the age of the unit, structural configuration, presence of anomalies, etc.

Best Practice: For a new hull RBI plan where operational data and degradation patterns are not yet defined, corporate and engineering knowledge of expected degradation should be made, initially a more conservative estimation to set inspection frequency, then validated and utilizing common updating techniques, kept evergreen over the asset's life to validate the plan. This knowledge should derive from either experience from other similar units or reflecting typical intervals found in industry codes and class rules. This is primarily important for high-risk components or areas. As part of regular RBI plan updates, once asset-specific degradation rates and trends are determined, inspection frequency can be validated made asset specific. Changes to typical prescriptive frequency of inspection require plan robustness and rigor and should be discussed and agreed upon with class as part of the RBI Guide approval process.

Best practice: Utilizing selective data collection efforts and data clean-up can directly impact the sustainability of the RBI program. Noting that the data collected often containing some unwanted information, is unstructured, or improperly formatted. Organizing and filtering the data to know what data is needed to act upon inspection results (need to expand the scope while actively executing), to interpret and act upon anomalies with proper risk prioritization, and the utilize all results in plan validation and updating. All the above are important steps to ensure the RBI program remains effective.

Best Practice: For existing units, optimization of frequency of inspections has a direct dependence on the quality of data available and the experience of personnel involved in the decision-making process. Further, it is important to consider the following F(P)SO specific issues:

- Open anomaly monitoring and any temporary repairs that warrant monitoring and planning for permanent repair
- Need for maintaining corrosion protection systems (ICCP, coatings, anodes)

RBI PROGRAM AND CLASSIFICATION

A well-produced RBI plan builds on class and industry experience to provide for inspection techniques and prioritization of inspections that are well suited for the unique characteristics of offshore assets.

An effective RBI program provides a logical, risk-based, and continually justified approach to inspection plan development and execution rather than introducing radically new concepts.

The development of a structural integrity management (SIM) program starts with a class rules-based foundation, and is adjusted based on asset considerations, class input and key stakeholder engagement (operator, owner, oil company, regulatory agencies, flag). The RBI program uses more asset-specific sources of information in the initial development, building a customized set of inspection requirements that takes into account the asset characteristics as well as other dependencies such as environmental conditions, degradation mechanisms and other structural properties.

Through the RBI program, class requirements are adapted to the asset in question. An approved RBI program replaces the prescriptive class requirements, becoming the new mandatory inspection regime while remaining compliant to class rules.

Additional details on the necessary elements of the plan and the steps to achieve full development can be found in the ABS *Guide for Risk Based Inspections for Floating Production Installations*.

Once an RBI program is developed, the RBI plan is to be submitted for class approval, detailing all structural critical elements, inspection intervals and inspection methodology for each of those points. Annually, a review meeting is to be held to review items in the plan based on inspection results and any changes to the RBI assumptions, and to update the plan accordingly.

During the RBI inspections, ABS surveyors will oversee RBI plan execution to be carried out by the inspection team as part of the Hull Continuous Survey applicable to the RBI plan. Please note that operators may have specific, more detailed work packs or work instructions to be used by their inspectors, which may be beyond the RBI plan approved by ABS.

Surveyors will typically execute the below tasks:

- Verify that scope of inspection in the work packs meets approved RBI plan and also covers the necessary objectives for class requirements
- Verify qualifications of personnel and subcontracted service supplier firms
- Supervise the process, review results and sign off on work completion prior to closing tank/compartment (RBI and class items)

- Recommend actions based on suspect areas and RBI findings, or recommend repairs depending on findings. We note that engineering may need to be involved to decide on the proper repair based on the risk aspects
- Verify RBI program is being correctly implemented and kept "evergreen" including updating the RBI plan after inspection are completed or more data is received
- Oversee repair activity, as necessary, in conjunction with the above
- Verify all anomalies that require resolution by the owner have been satisfactorily addressed and those that remain open are tracked and logged for continual monitoring as needed and incorporation into the next inspection scope for follow up.

Best Practice: Plan Health Meeting – Owner/operator shall conduct a plan health meeting every three to five years to review the overall plan health in line with initial plan development assumptions, any needed MOC based on field changes, initial degradation rate validation, plan validation methods via digital/data driven means using digital twins and their components with the aim of setting to course for the plan for the next three to five years.

Best Practice: Annual RBI Kickoff/Workpack Meeting – Owner/operator submits to Attending Surveyor/Local Office an annual package prior to the meeting that includes the inspection plan for the current campaign, prior inspection results and anomaly repair and monitor plans, and any relevant changes proposed to the RBI program from that approved, to be discussed and agreed upon before commencement of scope in field. This meeting shall include the Service Supplier inspection team lead(s), attending Surveyor, Company Subject Matter Experts (OIM, Marine Technical Authorities, Business Unit Lead, etc.), and engineering, as required. Inspection workpacks should be reviewed at this meeting to ensure all parties involved fully understand the requirement and procedures to be in place.

DATA MANAGEMENT

Data management is an important part of the maintenance of an effective RBI program. Data related to design and inspection are at the center of the RBI program to keep the plan accurate and up to date. In recent years, the digitalization of such data has become more prevalent as a means to automate, process, and utilize this data for continual RBI plan validation: Such approaches include one or more of the following:

- Data-driven approaches monitoring load, or response (sensor based) or via metocean data in tandem with condition history updating and structural analysis tools to provide better understanding of degradation rate(s) effect on structural integrity.
- Application of advanced remote inspection technologies and the means to process the larger volumes of data for RBI plan and human consumption. Such tools are often incorporating the use of AI-based techniques such as image processing, machine learning (ML), and natural language processing (NLP) to reduce the human burden to review and process such volumes of data.
- Use of digital twin concepts to assist in tracking critical asset integrity information on both sides of the failure equation (load vs. resistance). These include tracking both load and condition histories to validate RBI plan assumption as well as the models being used to keep those plans evergreen.

Best Practice: RBI plan to be dynamic and under continuous feedback loop to account for:

- Possible re-confirmation of the risk assessment, risk ranking and inspection plan
- Continuous inspection history
- Observed industry advances/knowledge
- Experienced trends for degradation
- Changes in asset operations resulting in modified loads

Best Practice: The implementation of a dynamic dashboard of asset integrity status such as a digital twin or a structural health monitoring system as well as an overall RBI plan health barometer to provide a transparent overview of asset integrity to regulators, company leadership and/or charterers.

Best Practice: Use of sensor data to calibrate an RBI plan, as follows:

- As a means to calibrate the actual global response of the asset (motions, stress, fatigue) in the utilized models
- As a means to directly monitor critical locations for confirmation of integrity (worst case or leading indicating indicator locations that are also part of RBI scope)

ANOMALY MANAGEMENT

Part of any F(P)SO inspection regime, whether prescriptive or risk-based, is in the prioritization and management of anomalies and findings. Under an RBI program, managing anomalies found during inspections requires continuous tracking, planning, and action. Potential recommended alternatives when an anomaly is found includes:

- No action, anomaly not forecast as integrity issue
- Monitor, observed degradation may become problematic
- Repair where current condition compromises integrity

Note: monitoring frequency will be established during plan development and is typically dictated by the extent of the degradation and severity of the consequences.

Best Practice: Maintain an anomaly register to track and manage anomalies, to be reviewed before each survey. The register is to be developed based on each individual operator practice. However, a sample can be provided by ABS on request. Risk assessment coupled with engineering analysis is often used to prioritize the open anomaly register. The risk tolerance is often based on the operator's corporate risk policies. However, the risk assessment should also consider the opinion of class society experience and understanding of both likelihood and consequence of escalation of open anomalies. At the end of the process, both the operator and ABS should agree on the actions, plan for closure and repair, monitoring, and the inclusion of same as conditions of class.

Best Practice: Ensure alignment of class survey findings and anomaly register, noting that owner's criteria may be stricter than class (i.e. an anomaly may not always be a condition of class).

Best Practice: Resolution and closing anomalies

- Make monitor/repair decisions as required. Use of risk methodology is common for both current and projected risk. If current risk condition of the structure due to the anomaly is above the acceptable risk level, repair is required
- Develop supporting analyses/justification for decision, as necessary and submit analyses and supporting documentation (anomaly reports, repair drawings, etc.) to class for approval
- Implement anomaly resolution
- Surveyor attendance as required, update Survey status

Best Practice: For all anomalies, operator to review implication of inspecting similar structural details within the tank and then the F(P)SO. Since the structural design typically repeats connection details across the hull, an anomaly found in one element may also be found in other elements with identical configuration.

IMPLEMENTATION OF RBI

The implementation of the RBI program is dependent on the type and age of asset, the availability of data, amongst other factors. Below are a few best practices acquired from lessons learned in the industry through several assets with RBI program.

Best Practice: On new construction or conversion, consider RBI plan to be a deliverable from detailed design engineering phase. The plan is more effective if developed in collaboration with operations personnel.

Best Practice: Effective handover of RBI plan to operations

- Operations should vet and own the SIM/RBI program
- Confirm SI/RBI plan as developed is workable within Business Unit (BU) resources up front

Best Practice: Plan Execution

- Scope often changes from year to year due to unforeseen events
- Key point is to inform a pre-determined stakeholder list, and plan ahead
- Pre-distribution of plan and annual pre-meetings are a must
- Although required by Class, periodic SIM/RBI plan health check and update is highly beneficial to the entire program. Frequency may vary based on the asset and other aspects, to be discussed and agreed upon with class

Best Practice: Implementation Challenges

- Communication to internal stakeholders is key: the RBI plan changes less frequently than the stakeholders
- Old paradigms to be changed: RBI presents an alternate approach to inspections that although in fully compliance with class rules, it doesn't follow the traditional class inspection regime. It is important to educate personnel and inspectors on how RBI works and how it satisfies class requirements

It is important to note that the incorrect implementation of the RBI program may leave critical elements unaddressed and therefore risks unmitigated. This potentially exposes the facilities, the operations and the personnel to a different set of risks that have not been accounted for in the development of the RBI plan.

Best Practice: The annual review of the RBI program is of extreme importance in order to confirm the plan has been properly implemented. If any implementation failure is detected, additional risk assessment may be required and update of the plan may be necessary. Please note that this is also a class requirement.

IMPORTANT POINTS

- RBI is a dynamic program that takes into account the degradation pattern and the effects of eventual operational changes.
- In a structural RBI plan, the class requirements get adapted to the asset in question. The RBI plan is not a parallel or a substitute for class. As such RBI planning is well suited for unique offshore assets. However, survey and RBI activities must be managed in tandem with the result being that the RBI plan and the crediting of the items for class happen together while also ensuring that all Statutory and key class item requirements are covered as part of plan execution.
- RBI is a means to manage integrity, not a tool to defer integrity management tasks.
- RBI does not preclude class involvement, but it re-prioritizes the surveys from prescriptive, calendar based, to a tailored asset-specific program with a schedule and scope of inspections optimized based on risk.
- Often a key aspect of plan development health and execution is continuously educating and aligning the people involved via continual communication. An RBI plan will often change much less frequently than the people do.

PUBLICATIONS

INTERNATIONAL STANDARDS

Below are several domestic and international standards dealing with RBI, primarily under the integrity management standpoint.

- API RP 580 – Risk-Based Inspection
- API RP 2SIM – Structural Integrity Management of Fixed Offshore Structures
- API RP 2FSIM – Floating Systems Integrity Management
- API RP 2MIM – Mooring Integrity Management
- API RP 2RIM - Integrity Management of Risers from Floating Production Systems

ABS RULES AND GUIDES

ABS Rules and Guides have provisions for the application of Risk-Based Inspection, and the following Guide has been issued to provide requirements for the development and implementation of an RBI plan:

- ABS *Guide for Risk-Based Inspection for Floating Offshore Installations*
- Other ABS publications that may be used to assist with the development and maintenance of an effective RBI program are listed below:
- ABS *Guide for Risk Evaluations for the Classification of Marine-Related Facilities*
- ABS *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Industries*
- ABS *Guidance Notes on Mooring Integrity Management*
- ABS *Guidance Notes on Production Riser Life Extension*

CONDUCTING REPAIRS WHILE OPERATING

OVERVIEW

OBJECTIVE

The offshore industry faces challenges in managing and conducting timely and effective structural repairs on FPSOs and FSOs (or F(P)SOs) without impacting production. Due to their oil storage function and the need to conduct those repairs while operating, F(P)SOs are particularly vulnerable to the performance of structural repairs, and measures are to be taken to ensure safe conditions for the repair crew, the asset, and the environment.

This paper provides best practices for safely completing structural repairs during operation with minimal impact on production and in accordance with Classification and international standards.

CHALLENGES

F(P)SO operations are complex and involve many technical and logistical tasks that ultimately reflect on the production and safety performance of the unit. As F(P)SOs are stationary units and typically operate for the entire lifecycle at the same location, removing the F(P)SO from location and bringing to drydock for repairs is often not a viable option. As such, any repairs are to be executed on the offshore location and the logistical difficulties associated with such work much be managed both practically and safely.

Operators face several challenges in safely executing structural repairs on board the unit while in operation. Below are some examples:

Technical:

- Isolation of tanks
  - The compartment to be repaired is to be isolated and removed from service. In some tanker-to-F(P)SO conversion, positive isolation may not be achievable without entering the tank and installing mechanical blinds within tank systems and interconnected bottom cargo lines.
  - Adjacent tank to the repair location typically must be emptied, cleaned and gas-freed.
  - Reduction of storage capacity due to out of service tanks for repairs causing possible disruption to production rates.
- Hot work
  - Hot work is not allowed in flammable or explosive environment.
  - Hot work for in-tank repairs requires additional localized cleaning of remaining sludge and sediments after tank washing, which is a labor and time-consuming task.
- Confined Space Entry
  - Access to repair locations – for instance, areas at height (bracket toes – fatigue etc.) require suitable access and work temporary platforms for completing repairs.
  - Tank ventilation and atmosphere management SIMOPS with production systems in the topsides.
  - Bottom line expansion joints are vulnerable to failure and potentially another source of hydrocarbon release within space to be repaired (N.B. Water plugs in bottom lines should be considered as described in OCIMF Cargo Guidelines for F(P)SOs).
- Offshore and SIMOPS Repair Practicality
  - The means of repair must have a degree of portability to be able to be brought into a tank without affecting the SIMOPS aspects and also material handling difficulties in situ. In this regard, repair of deficient structure, while often under operating loads, involve a series of means to crop and renew within practical limits of strong backing the cropped section, but also with a need to prepare and add stiffening and panel-breakers to a deficient plate when such cropping is not feasible.
  - There is often a need due to SIMOPS to work within an atmospheric tent (or "igloo") to shield hot work from hazardous areas. Ventilation and personnel safety are of paramount importance in these instances.
  - Hull envelope issues also present huge challenges while on station, particularly below the waterline. Solutions such as water backed or wet welding or temporary cofferdams are often implemented.
  - Sometimes, temporary, or permanent non-hot work repair techniques are employed when operations or SIMOPS restricts the use of hot work due to safety concerns.

- Tank cleaning
  - Cleaning F(P)SO structure – in particular first-generation single hull F(P)SOs where the bottom longitudinal stiffeners and transverse web frame structures within the tanks are configured in a way that readily trap sludge and sediments. Also, for F(P)SOs, cleaning operations are conducted much less frequently than those in tanker operations, thus allowing for an increased buildup of deposits, scale, silt and sludge within the bottom bays.
  - Understanding by personnel involved including management, of the value of programmed crude oil wash .
  - Fixed tank cleaning machines "shadow areas" within the tanks. Typically, areas under the deck frame structures or beneath stringers, and areas not in direct path of the oil or water jets.
  - Removal and disposal of sludge and sediment waste from cleaning the tanks.
  - Repairs on the submerged parts of the hull that may require external cofferdams, pre-heating, etc. (i.e., challenges associated with water back welding in addition to any repairs requiring steel renewal).
  - Potential need to perform temporary repair while developing repair plans and obtaining necessary approvals (internal, Client's, Class) for permanent repairs with long lead time.
  - Availability of local technical personnel to develop proper welding procedure and execution.
- Preparation for access
  - Electric power, compressed air, and water availability on main deck near tank access to be carefully considered.
  - Ventilation routing on main decks from the tanks.
  - Size, location and number of access hatches into tanks, as a larger diameter may be needed for repair material handling.
  - SIMOPS during tank confined space entries (e.g., internal cargo transfer, cargo offloading to export tanker, support vessel activities, etc.) may limit tank access times and create onerous or misunderstood risk profiles to tank work.
  - Weather impacts delaying work execution (e.g., lightning, confined space entry restrictions, sea states impacting hull motions when utilizing rope access, greenwater restricting deck access, etc.)
  - Regional security impact: personnel conducting confined space entry need to be allotted time to evacuate the tank and make way to temporary refuge. Depending on level of threat, confined space entry may be delayed.

Logistical:

- Safety personnel/confined spaces entry personnel rescue plan: availability of safety and medical staff during tank entry activities in case of emergency including availability of medevac transportation in the event of any serious injury.
- Personnel trained for confined spaces entry.
- People on board (POB) constraints while carrying out repairs recognizing the need to potentially accommodate additional repair, inspection, safety crews, etc.
- Identification of critical path activities (i.e. tasks which may cause delays to repair and survey completion).
- Availability of materials and equipment to execute the repairs.
- Time to plan and construct scaffolding if required.
- Availability of class-approved welder(s).
- Importation aspects for spare parts, materials, equipment, tools, etc.
- Transportation of repair crew and repair materials.
- Lifting devices limitations: crane capacity and reach, A-frames or portable jib cranes for material handling into the tank, etc.
- Personnel: Visas, technical qualifications, proper immunization, etc.

Additional challenges are also faced by the owner/operator of the facility and may involve financial aspects (repair budget, cost overruns, loss of production revenue), management aspects (internal approvals, impact on other stakeholders), scheduling, social responsibility aspects, environmental impact aspects, amongst others, which are not part of the discussions herein.

INDUSTRY BEST PRACTICES

Executing F(P)SO structural repairs while operating is a situation all operators typically face during the lifecycle of the F(P)SO, even under the most rigid asset integrity management regimes. To overcome some of the challenges previously discussed, owners and operators must find solutions that will produce the expected results while having the following key expectations in mind:

- Safety of personnel, environment and asset
- Reduced impact to production
- Achieving effective results
- Compliance with classification and statutory requirements

Below is a collection of best practices to be considered when facing this situation.

PLANNING

Front end planning is one of the most important activities leading into a successful repair campaign. When planning for offshore work, it is strongly recommended to take a holistic approach to safety, including planning for evacuation or injured personnel, emergency response and tank preparation for confined space entry. Planning involves several activities, and includes:

- Identify areas to be repaired and the extent of the repairs: a detailed material take-off is required so proper materials and suitable equipment will be available during the execution of the repairs.
- Repair methods proposed are to be both practical to execute offshore (can workers enter and work through the available opening) and safe to execute given the difficulties of working at height, or under sea motions, for the personnel involved.
- Identify all risks and develop mitigation strategies that are achievable and realistic. A detailed risk assessment should consider aspects such as:
  - Risks involving personnel: accessing the tank, confined space work, fatigue, temperature-related issues, etc.
  - Safety risks: potential for fire and explosion, injured personnel removal and treatment, tank atmosphere, with special care for areas where naturally occurring radioactive material (NORM) is present, pyrophoric materials, etc.
  - Risks involving staging area(s) to be accessed for inspection and repairs.
  - Risks involving manual cleaning and removal (buckets and scoops) of remaining sludge and sediments.
  - Hot work risks: atmosphere testing and continuous monitoring, localized hand cleaning of repair area and surrounding areas, adjacent tank preparation and boundaries definition
  - Risks involving material handling: dropped objects, availability of proper rigging supplies, on-deck and in-tank transportation, etc.
  - Risks involving execution: difficulties in properly executing surface preparation and pre-heating, potential issues caused by welding, etc.

  NOTE: ABS has issued the following two publications addressing the risk assessment practices and application for the marine and offshore industry that can be used as guidance for the risk assessment activities described above:
  - ABS *Guide for Risk Evaluations for the Classification of Marine-Related Facilities*
  - ABS *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Industries*
- Develop detailed repair specifications that are suited for offshore execution, including qualified welding procedures for water-backed welding (if applicable).
- Determining, defining, and agreeing upon an appropriate approach for hot work repairs is a time-consuming activity. Planning should start well ahead of the execution to ensure every aspect and risks have been considered.
- Provisions that allow hot work during the operation phase should be accounted for in the design, as well as in the development of policies and the safety management system for the installation.
- Although the high-level objectives are to avoid hot work on producing facilities, it may be inevitable during the long life of the unit onsite. Stakeholders must be cognizant that hot work and repair may be inevitable.
- Consider increased level of permit-to-work management to improve safety in the operations. If any unforeseen events should affect the execution, work should stop and be reassessed. Conducting toolbox talks prior to each work period is important and stop-work authority needs to be clearly conveyed.

- Confirm availability of fire-fighting equipment and other safety/rescue equipment (stretchers, first aids kit, etc.) while repairs are being carried out, as well as the competency of the safety crew to ensure that the rescue plan is feasible prior to starting work in the tank start.
- Confirm availability of correct welding supplies, materials and tools necessary for the repairs, and coating supplies.
- A detailed scaffolding plan should be developed. Usually, repairs at higher reaches (e.g. cross ties or under deck) will require either hanging staging or scaffolding from the bottom. Regardless of the amount of scaffolding needed, it must be ensured that they meet the required safety standards. Note that modern F(P)SOs may be provided with permanent means of access, which may reduce the need for additional scaffolding.
- Schedule repairs aligned with production turnarounds or planned shut-ins when possible and permitted by class.
- Evaluate SIMOPs, considering all other operations that will take place while the repairs are being conducted, including onboard and off-the-unit activities (supply boats, support vessels, etc.).
- Potential considerations from SIMOPS may include:
  - Increased risk of fire or explosion
  - Detection and mitigation of fire or explosion
  - Increased risk of entrapment in the confined space
  - Increased risk of gas release
  - Increased risk of loss of containment

A SIMOPS review and approval to be completed in advance of any tank entries with focus on operational factors such as production, maintenance, cargo transfer, cargo offloads, bunkering, weather, lifting operations and supply boats are also considered.

- Determine the engagement of the classification society surveyors and plan accordingly (considering timing of engagement, POB availability, transportation to-and-from the facility, etc.). Also determine the need for engineering reviews of repair plans.

Special attention should be given to legislative and regulatory aspects in the country of operation. Several countries require strong engagement with local regulatory agencies (Maritime Authority, Petroleum Agency, and others) in offshore activities, therefore it is necessary to engage pertinent authorities and obtain necessary permits and licenses to execute the repairs. Other aspects to be considered include importation arrangements and import duties for materials and equipment being brought on board specifically for the repair campaign, and the need for attendance of local regulatory agencies for inspections or audits.

As each facility, situation, country of operation, and scope of repair has its own unique features, needs and requirements, it is important to engage the necessary stakeholders at the appropriate time to properly plan the execution of the job, as well to identify any items that may not be evident to the site operators or onshore staff.

ENGINEERING

Repair engineering is highly recommended once the need to repair is identified. A higher success rate is typically achieved when engineering is executed upfront, primarily when the repair campaign is complex and expected to be extended for a period of time.

Repair engineering activities should take into consideration not only the repairs themselves but also any potential impact or consequence caused by an incident during the execution of the repairs. Several aspects requiring engineering solutions in the repair operation include:

- **Development of specifications:** material to be used in the repairs, paying special attention to the original construction materials and compatibility with the repair supplies, welding consumables, coating materials for touch-up or re-coating, repair equipment, lifting devices and material handling equipment, etc.
- **Development of procedures:** repair methodology, welding procedure, welding plan, grinding plan, crack arresting plans, coating procedure, material handling procedures, etc.
- **Safety plans:** verify that the existing emergency response plan, emergency evacuation plans, confined space entry and rescue from heights plans, egress routes, hot work and firefighting plan, and other plans and procedures required for normal operations cover any potential consequences of the repair activities. If any safety aspect related to the repair operation is not covered by the existing plans, special addendums should be developed and approved by the required parties (Class, Flag, Coastal authorities, etc.).

- **Transportation and lifting plans:** apply to materials, equipment, tools and supplies; it should cover transportation aspects from the shore base or dock to the offshore facility; lifting of the parts with the onboard crane; transportation on deck to the repair location; lifting and lowering inside the tank or compartment; handling of the material and equipment inside the tank, as well as removal of debris and clean-up after repairs are complete and prior to put the tanks back into operation.
- **Marine plans:**
  - Tank isolation where blanking blinds or other means that need to be inserted on bottom lines to obtain positive isolation.
  - Impact to stability analysis, loading conditions, or any other aspect not already covered by original design conditions.
  - Drawings and analysis of the repairs as well as the after-repair conditions that may impact the strength, fatigue and buckling characteristics of the local structures.
  - Potential impact in case of an incident while performing repairs, primarily if it includes side shell, bottom plates, or ship-side valves.

    NOTE: ABS has addressed the process of identifying and assessing the effects of structural loads arising from accidental events in the ABS *Guidance Notes on Accidental Load Analysis and Design for Offshore Structures*. The notes in this publication can be used to guide the engineering analysis.
- **Staging plan:** for areas of repair a staging plan is to include scaffolding design and the need for weight bearing scaffolding if required for lifting/lowering materials to and from repair position.
- Development of checklists and material take-offs to ensure all activities and supplies are carried out as planned.
- Development of an inspection and test plan (ITP) for the repair activity to be shared and signed off with all involved stakeholders.
- The risk assessments discussed in previous sections are to be considered when preparing engineering plans and procedures. All risks identified during the workshops must be addressed and mitigated.

EXECUTION

In the execution of these structural repairs, the following key aspects should be taken into consideration:

Confined Space Entry

Confined space entry is a safety critical task when executing structural repairs in tanks, and it is critical even without introducing ignition sources. It is one of the key safety concerns facing the industry. Actions are required to be taken to mitigate the typical hazards of confined space entry, especially when hot work is being carried out:

- Risk of asphyxiation due to oxygen deficiency and exposure to toxic and flammable chemicals is one of the highest risks. It is of utmost importance to maintain a safe, breathable atmosphere in the tank. Thorough gas testing procedures prior to entry to prove that tank isolations are in place (refer to section 1.2 above). Forced ventilation from a non-hazardous area with in-line gas detection will provide assurance that the risk of the confined space atmosphere will remain breathable and non-explosive.
- Human factors: exposure to extreme temperatures, poor or limited visibility, and extreme noise.
- Safety aspects: restricted access/escape typically makes quick rescue in emergency situations more challenging.
- Wet surfaces and falling objects.
- Fire and explosion.
- Electric shock.

Confined space entry procedures should be in place as part of the safety management System (SMS) of the unit. If the existing procedure does not appropriately address the execution of repairs, or the specific repair method being applied, a specific procedure is to be created.

OCIMF publication ISGOTT has specific details about confined spaces entry and other useful information related to tankers that can be directly applicable to F(P)SOs. As a supplement to ISGOTT for F(P)SO's operators, OCIMF provides additional guidance with the publication Cargo Guidelines for F(P)SOs. OCIMF also has the publication Guideline on Marine Assessment of FPSOs – Assessment Criteria and Questionnaire that also has details on tank entry and other important information. This publication is meant to be an assessment tool/questionnaire to assess the health of F(P)SO operational integrity/SMS against industry standards and best practices rather than a specific operational guidance publication.

Given specific hazards associated with entering a cargo tank, personnel involved in the activity should adopt various recommended safety practices to reduce risk. For example, oil-coated, steep sloping ladders in excess of 5 m long are not uncommon in cargo tanks. To reduce risk of injury on these ladders, it is recommended to descend the ladder facing the steps rather than using it as a staircase as slip and trip hazards present the highest risk of injury requiring a casualty evacuation. Other control measures for reducing these risks include providing good illumination within the space and cleaning access ways and ladders prior to commencing the work tasks.

Hydrocarbon Isolation

Another major risk for tank entry for repairs while operating is that there are hydrocarbons being stored and transferred through piping systems throughout the unit. The following activities must take place prior to any tank entry to ensure safe access:

- Tank cleaning, inert gas purging and subsequent gas freeing

  NOTE: ABS has issued the ABS *Guide for Enhanced Cargo Tank Cleaning* for units provided with permanently installed cargo tank cleaning system along with portable tank cleaning machines.
- Positive isolation of cargo into the tank: Single block valves are not sufficient to ensure the tank is isolated. Proper isolation arrangements should consider the use of blind flanges, double block valves with bleed, and removable spool pieces designed specifically for tank isolation. A less efficient means but equally effective is the removal of sections of pipe leading into the tank or to the isolation valve.
- Isolation philosophy in design is to be carefully evaluated. On a new construction, the operational differences and the use of marine standards versus production standards should be considered. This has proven to be more challenging on conversions, but it needs to be considered on new-built facilities as well.
- The risk of the isolation activity needs to be considered as well, when deciding the optimum isolation method. When using valves, efforts must be made to verify isolation and maintain the valves in the closed state (e.g., by locally isolating hydraulic lines), and use proper locking and tagging procedures.
- Very often inspections are delayed due to the difficulty in achieving the isolation necessary for safe confined space entry. For converted F(P)SOs that inherit their design from tankers, it is usual to encounter issues in achieving corporate isolation standards. As such, it is recommended to take the specific F(P)SO operational characteristics into account during the design for the conversion, creating a positive isolation of adjacent tanks.
- These items above are also covered by the ISGOTT's publication "Cargo Guidelines for F(P)SOs".

Execution of Repairs

Items to be considered when executing the structural repairs to minimize risks generated by the repair procedure:

- Planning period: Confirm all necessary equipment involved in the job execution is available and in working order, utilities are available (electrical, air, etc.), and support is in place before personnel mobilized to go offshore to conduct work. This includes, but is not limited to: welding and cutting equipment; power and hand tools; welding consumables including welding gas; grinding tools and consumables; power distribution equipment; compressed air hoses and connectors; lifting, rigging and transportation equipment; lighting arrangements and devices (including explosion proof or intrinsically safe fixtures); construction aids; as well as other eventual materials such as ropes, slings, shackles, batteries for flash lights, etc.

- Repair area is to be prepared to the necessary standard to ensure that no hotspots or high-tension spots will be created after welding is complete.
- Surface preparation: follow coating manufacturer's recommendation for surface preparation to ensure proper adherence of coating repairs. Consider the need of dehumidification system to achieve the proper environment for coating repairs.

  NOTE: ABS has published the ABS *Guidance Notes on Maintenance and Repairs of Protective Coatings* with important information and guidelines on effectively executing maintenance and repair of coatings, primarily in cargo and ballast tanks.
- Continued monitoring and hazard management to ensure the activities are executed and the hazards are controlled.
- Continued barrier management verification to ensure the safeguards are in place and safety is not jeopardized during the execution of the repairs.

JOB SAFETY ANALYSIS (JSA)

It is generally accepted that nearly every task performed onboard an F(P)SO has hazards and associated risks that must be managed. This is even more prominent when the task involves structural repairs that often requires confined space entry and hot work. A hazard is often associated with a condition or activity that when left uncontrolled can result in injury or other health consequence.

According to OSHA, "A job hazard analysis is a technique that focuses on job tasks as a way to identify hazards before they occur. It focuses on the relationship between the worker, the task, the tools, and the work environment." A JSA should focus on the identification of uncontrolled hazards and the steps taken by the workers to eliminate or reduce hazards to an acceptable level of risk.

The JSA process must consider the accident history of the similar tasks and at the worksite, even if they are near misses. Using the guidelines provided in the OSHA's publication Job Safety Analysis, the following steps should be taken on the development of a JSA for structural repairs while operating:

- The first step of the process should be to identify the scope of the work (what, where, and how, etc.), as this drives an understanding of the hazards involved with the task.
- All personnel involved in any form or manner in the execution of the structural repairs should be involved
- Review the history of incidents or accidents on similar activities. This is important to not only learn from previous incidents, but also to impart a sense of vulnerability. One key for ensuring safe behaviors is to eliminate any perception by the individuals performing the work that an accident/injury cannot happen to them.
- Conduct a preliminary job review using the experience of the personnel that will execute tasks. Any ideas or opinions should be considered in this brainstorming session.
- Build a list of identified hazardous jobs and rank them, setting priorities for analysis to the jobs that present unacceptable risks.
- Outline the steps and tasks necessary to execute the job in order to clearly identify every step necessary and the related hazards.
- Determine what can go wrong, consequences, manner that it could happen, any contributing factor, and the likelihood of occurrence within each step of the task.

Once completed, the JSA needs to be acknowledged and understood by the personnel involved in the repair activities and any ancillary activities in support of it.

One of the most important components of the application of the JSA is the STOP WORK culture. Stop Work Authority procedures provide personnel the power to STOP WORK when a perceived unsafe behavior, unsafe condition, or a hazard is identified. If a worker considers that a condition on the job site becomes too unsafe or hazardous for the execution of the work, the worker has an obligation to stop the work until the condition is improved.

The JSA is a dynamic document that should be reviewed periodically to ensure it remains current and accurate. It is particularly important to review the JSA if an accident/incident/near miss occurs at the jobsite during the entire operation involving the structural repairs.

Note: In practice, missing the detailed scope of work often drives the use of a generic "tank entry" JSA that may not address all hazards and risks since it does not consider the reality of the work to be performed. The use of generic JSA's without defined scope should be avoided.

PUBLICATIONS

INTERNATIONAL STANDARDS

Oftentimes, international standards are either not readily available, or not clear/prescriptive enough, or not detailed enough to cover the requirements for conducting repairs on board with the unit in operation.

However, some aspects discussed in this document are covered by international standards listed below:

- International Safety Guide for Oil Tankers and Terminals – Sixth Edition – OCIMF, 2020 (ISGOTT6)
- OCIMF - Cargo Guidelines for F(P)SOs (1st Edition)
- NFPA 306 – Standard for the Control of Gas Hazards on Vessels
- International Association of Classification Societies - IACS Recommendation No. 72 – Confined Space Safe Practice
- U.S. Occupational Safety and Health Administration OSHA Standard 1910.146 - Permit-required confined space
- UK Health and Safety Executive UK-HSE "Confined Spaces – A brief guide to working safely"

ABS RULES AND GUIDES

ABS Rules and Guides provide requirements and guidance for the safety aspects of the design and execution of the repairs, as well as defines criteria for selecting methods, procedures, material specifications, as well as for the acceptance of the repairs. As most of the issues discussed in this document are of operational nature, they are not specifically addressed by ABS Rules and Guides.

The ABS Rules and Guides mentioned in this document are listed below in the order they appear in the text:

- ABS *Guide for Risk Evaluations for the Classification of Marine-Related Facilities*
- ABS *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Industries*
- ABS *Guidance Notes on Accidental Load Analysis and Design for Offshore Structures*
- ABS *Guide for Enhanced Cargo Tank Cleaning*
- ABS *Guidance Notes on Maintenance and Repairs of Protective Coatings*

TRACKING OF COMPOSITE NON-PERMANENT REPAIR

OVERVIEW

OBJECTIVE

This paper provides guidance regarding the monitoring, examinations and assessment of non-permanent composite repair techniques and processes on stationary production facilities (e.g. FPSOs).

As these non-permanent repairs typically address conditions of class (COC) that were previously found not in compliance with the class or statutory requirements, it is vital that their satisfactory condition and suitability for continued use is confirmed on a regular basis.

This paper provides some guidance and direction to revalidate their continued suitability and thus the overall satisfactory condition of the offshore asset.

CHALLENGES

Unlike marine vessels and drilling units, FPSOs and other stationary production facilities cannot easily relocate to a drydock or other repair facility for repairs. In many instances, there are restrictions regarding hot work on these facilities. Also, a stationary production facility may not have all of the necessary resources (materials and personnel) onboard or at a nearby location to carry out full and permanent repairs.

As a result, there is a higher propensity for temporary repairs to be used prior to full and permanent repairs being carried out. Conventional metallic repairs are not possible to be carried out on many occasions and composite repairs are often implemented in these situations. Additionally, some repairs may be located in areas with restricted access and may not lend themselves to daily, weekly, or monthly validation checks. Further, some types of repairs may prohibit the detection of new issues.

Different repair techniques and systems may have unique requirements for re-examination. These differences could be based on the type of material utilized, type of repair (structure or piping), the location of the repair, intended service, service life, and the date installed or applied. If an offshore production asset has more than one repair system implemented across several locations on a unit, the steps necessary to reevaluate the temporary repair may not be clear.

Lastly, the above concerns could be further complicated if there are tens or hundreds of non-permanent repairs implemented.

INDUSTRY NEED FOR THE DEVELOPMENT OF BEST PRACTICES

CURRENT STATUS

While the maritime and offshore industries can use the installation guidance from the manufacturers as well as some standards relating to the analysis and application (installation) of composite repairs, there does not appear to be any guidance or standards for in-service validation and inspection.

RELATED INTERNATIONAL STANDARDS

- BS EN ISO 24817:2017 'Petroleum, petrochemical and natural gas industries - Composite repairs for pipework – Qualification and design, installation, testing and inspection'.
- ASME PCC-2 'Repair of Pressure Equipment and Piping'; Part 4 'Nonmetallic and Bonded Repairs'. This ASME document provides the details as to the necessary data that should be captured during the repair, section 402-3.2 and 402-3.3.

RELATED ABS PUBLICATIONS

ABS *Guidance Notes on Composite Repair of Steel Structures and Piping*:
To assist the offshore production industry, in 2019 ABS published *Guidance Notes on Composite Repair of Steel Structures and Piping*, in order to provide guidance on the usage of non-metallic or composite repairs. The ABS Guidance Notes provide guidance and direction on the following points: assessment, repair design, materials qualification, and installation (application onboard). In-service inspection intervals and criteria are mentioned but are not detailed, leaving the inspection strategy to be developed by the owner/operator.

Note that the ABS Guidance Notes are currently limited to site-specific offshore structures (e.g. FPSOs).

PATH FORWARD

With the expected growth of composite repairs in the offshore industry, there is a need to reliably validate the continued effectiveness by both the asset teams and surveyors. Criteria for effective inspection and allowable extension of different types of defects, eventually identified, based on reliable techniques needs to be developed. This can be complicated by the type of repair system, the selected repair material, the location of the repair, intended service, estimated service life, etc.

Therefore, to adequately manage these repairs, it is important to both capture the necessary installation data and to have an effective tracking system for the follow-up inspections. This data is to be updated, maintained, and retained onboard the production facility. It should be also regularly reviewed by the asset management team for compliance.

COMPOSITE REPAIR INSTALLATION AND IN-SERVICE DATA

At a minimum, to facilitate adequate tracking and validation, ABS recommends that the following data to be captured at the time of the installation of any composite repairs:

- Composite repair system
- Date of installation
- Expiry date of the repair
- Defect or anomaly number
- Location
- Anomaly description
  - Type of anomaly (e.g. corrosion)
  - Associated anomaly inspection reports
- Associated condition of class (CoC) or finding number
- Type; structural or equipment/piping
- Type of repair; emergency, short term or long term
- Applicable drawing or plan
- Installation information
  - Installer information (name, certification of approval or installer)
  - Post installation testing and results
  - Provision of mitigations that may be required
- Inspection tag number
- In-service inspection
  - Intervals
  - Method
  - History
  - Inspecting body and any credentials
  - Acceptance criteria
  - Results of inspection with grading (e.g. satisfactory)
  - Confirmed effectiveness of any required mitigations
  - Any follow-up actions required (e.g. renewal or replacement of composite repair ahead of expiry date)
- Permanent repair information
- ABS approval of the system; ABS Type Approval reference
- ABS approval of the asset specific repair installation (as applicable); ABS approval letter number and date of issue

The above is to be provided to the attending ABS surveyor for review and acceptance during their attendance onboard the unit at the following times:

- Any time after an anomaly has been addressed via a composite repair system
- During periodic surveys for the maintenance of classification (e.g. annual surveys)

These are to be reviewed and discussed with the surveyor onboard the unit. The surveyor will use these in conjunction with an examination of the repair to confirm the suitability of any new repair or to revalidate the continued effectiveness of any existing repair.

Additionally, it is suggested that the following additional information be considered for inclusion on

- Any certification or inspector qualification information for in-service inspections
- Information as to the planned permanent repair
  - Schedule
  - Work order/purchase order
  - Feedback mechanism for adjustments in case of additional anomalies or issues are noted

For new repairs, the surveyor may issue a condition of class (or another finding type) to track the issue within the ABS Asset Database (Freedom).

INCLUSION INTO A PM OR CMM SYSTEM

In lieu of current tracking mechanisms that have been observed by ABS, these repairs and relevant information should be incorporated into the offshore assets preventative maintenance system (PMS) or computerized maintenance management system (CMMS). Incorporation into a PMS or CMMS would not only facilitate the adherence to an agreed maintenance regime but would also be able to provide objective evidence as to the condition of the repair to ABS or another regulatory agency during periodic inspections onboard the installation.

Additionally, the capture of standardized data via a PMS or CMM System, can also provide feedback to the manufacturers and regulatory agencies. This data could then not only validate the estimated service life of the composite repair system but may also serve as a baseline to consider an extension of service life.

RBI PROGRAMS

For units with an ABS Approved RBI Program, composite repair system inspection data, etc., may be included into the RBI program for the asset. These repairs are to be part of the overall RBI examination schedule.

PRE-APPROVED REPAIR PLANS

To facilitate acceptance, installation and data capture, operators may also wish to consider providing a consolidated composite repair plan for review and acceptance by ABS.

APPENDIX I — LIST OF ACRONYMS AND ABBREVIATIONS

ABS	American Bureau of Shipping
ALARP	As Low As Reasonably Practicable
API	American Petroleum Institute
BU	Business Unit
CCR	Cargo Control Room
CMMS	Computerized Maintenance Management System
COC	Condition of Class
COP	Cargo Oil Pump
COW	Crude Oil Washing
CSE	Confined Space Entry
ESP	Enhanced Survey Program
FPSO	Floating Production Storage and Offloading
ISGOTT	International Safety Guide for Oil Tankers
ISIP	In-Service Inspection Plan
ITF	International Transport Workers Federation
ITP	Inspection and Test Plan
MARPOL	International Convention for the Prevention of Pollution from Ships
MDPI	Multidisciplinary Digital Publishing Institute
MODU	Mobile Offshore Drilling Unit
NORM	Naturally Occurring Radioactive Material
OCIMF	Oil Companies International Marine Forum
OSHA	Occupational Safety and Health Administration, and agency of the U.S. Department of Labor
PMS	Preventative Maintenance System
POB	People On Board
RBI	Risk Based Inspection
RIV	Remote Inspection Vehicles
ROV	Remotely Operated Underwater Vehicles
SIM	Structural Integrity Management
SIMOPs	Simultaneous Operations
SOLAS	International Convention for the Safety of Life at Sea
SMS	Safety Management System
UAV	Unmanned Aerial Vehicle
VLCC	Very Large Crude Carrier
WG	Water Gauge

ACKNOWLEDGEMENTS

This document is the latest ABS initiative to support the industry to address the safety challenges in FPSOs. ABS thanks experts from the following leading companies in the FPSO sector for providing valuable comments to the earlier drafts of the manuscript.

- Bahamas Maritime Authority (BMA)
- Chevron
- ExxonMobil
- MODEC
- Petrobras
- Republic of the Marshall Islands (RMI) Registry
- SBM
- Shell
- United States Coast Guard

CONTACT INFORMATION

GLOBAL SUSTAINABILITY CENTER
1701 City Plaza Dr.
Spring, Texas 77389, USA
Tel: +1-281-877-6000
Email: Sustainability@eagle.org

NORTH AMERICA REGION
1701 City Plaza Dr.
Spring, Texas 77389, USA
Tel: +1-281-877-6000
Email: ABS-Amer@eagle.org

SOUTH AMERICA REGION
Rua Acre, nº 15 - 11º floor, Centro
Rio de Janeiro 20081-000, Brazil
Tel: +55 21 2276-3535
Email: ABSRio@eagle.org

EUROPE REGION
111 Old Broad Street
London EC2N 1AP, UK
Tel: +44-20-7247-3255
Email: ABS-Eur@eagle.org

AFRICA AND MIDDLE EAST REGION
Al Joud Center, 1st floor, Suite # 111
Sheikh Zayed Road
P.O. Box 24860, Dubai, UAE
Tel: +971 4 330 6000
Email: ABSDubai@eagle.org

GREATER CHINA REGION
World Trade Tower, 29F, Room 2906
500 Guangdong Road, Huangpu District,
Shanghai, China 200000
Tel: +86 21 23270888
Email: ABSGreaterChina@eagle.org

NORTH PACIFIC REGION
11th Floor, Kyobo Life Insurance Bldg.
7, Chungjang-daero, Jung-Gu
Busan 48939, Republic of Korea
Tel: +82 51 460 4197
Email: ABSNorthPacific@eagle.org

SOUTH PACIFIC REGION
438 Alexandra Road
#08-00 Alexandra Point, Singapore 119958
Tel: +65 6276 8700
Email: ABS-Pac@eagle.org

ABS

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