Converted Single Hull F(P)SO Challenges regarding Inspection, Repair and Maintenance.

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I. Abstract

FPSO conversion projects experimented a sharply increasing since 1996, many of them converted from single hull tankers built before 1985. First inspections have shown a number of failures of structural components indicating that hull integrity of these units will be a challenge as they should stay on station along the field life without go on dry-dock. Thus a rational inspection plan and maintenance need be set up in order to avoid or minimize the impact of inspections in the normal operation of the unit. Importance of the conversion is also outlined through return of experience on converted and guideline in the choice of the hull and the preparation of conversion works.

II. Introduction

Although new built F(P)SOs have been significantly increased during the last years, in particular for use in harsh environment zones and deepwater developments where huge are required, converted s are still a commonly chosen solution for milder environment like West Africa, South East Asia and Brazil. At the moment, with fully-booked shipyards, they are the best solution for fast tracks projects where earlier first oil is required.

Today there are approximately 111 FPSOs and 86 FSOs systems [10] in operation or available worldwide, approximately 70% are converted from trading single hull tankers built along the 70s and early 80s. Many of these units have been in operation already after 20-30 years and shall stay on site during at least more 10-15 years, where disconnection or removal from the moorings systems is not planned. That gives on one hand a good return of experience on the structure of that type of unit, but on the other hand a great challenge to maintain as long as reasonably possible these units on site.

The low price of single hull tankers is the main reason why conversion is still mainly a single hull point, despite the aging of single hull ships and their scarcity. The paper will discuss the types of single hull vessels, summarizing their main characteristics and the common way of assess the hull structure strength of these vessels. It will then focus on the possible repairs based on return of experience, and will end on the way to avoid costly repairs: a worthwhile conversion, efficient inspections and rational maintenance plan.
III. **Single hull vessels**

In service single hull vessels have generally been built between the mid 1970’s and 1995. After 1996 double hull tankers building have known a sharp increase, putting forward Japanese and Korean shipyards.

The selection of single hull tankers for a conversion project is leaded by the balance between the purchasing cost of the hull, lower for single hull ships than for more recent double hull ones and the refurbishments work, which depends on the age and previous maintenance of the ship.

The table below shows the price of tankers depending of their age. It also shows a separation in single hull tanker around 1985-86. After 1996 most of the vessels are double hull tankers.

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>1985</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2000</td>
<td>11.8</td>
<td>43.0</td>
<td>73.8</td>
<td>-</td>
</tr>
<tr>
<td>2001</td>
<td>12.6</td>
<td>35.2</td>
<td>79.2</td>
<td>82.5</td>
</tr>
<tr>
<td>2002</td>
<td>11.0</td>
<td>21.5</td>
<td>59.5</td>
<td>75.0</td>
</tr>
<tr>
<td>2003</td>
<td>13.0</td>
<td>32.8</td>
<td>52.0</td>
<td>65.4</td>
</tr>
<tr>
<td>2004</td>
<td>15.0</td>
<td>60.0</td>
<td>85.5</td>
<td>110</td>
</tr>
<tr>
<td><strong>Average sale price</strong></td>
<td>12.3</td>
<td>36.3</td>
<td>66.1</td>
<td>88.3</td>
</tr>
<tr>
<td><strong>Ships operating</strong></td>
<td>29</td>
<td>185</td>
<td>116</td>
<td>118</td>
</tr>
</tbody>
</table>

*Table 1 - oil tanker average sale price (source: CW Kellock & Co. Ltd.)*

III.1/ **Vessels built before 1985**

Conversion of single hull tankers built before 1985 have been a worthwhile alternative for FSO projects. Such vessels are relatively cheaper and their primary and secondary structures use to be stiffer than in hulls built after 1985, where high tensile steel has been extensively used.

A number of different designs can be identified, comprising American, French, German, Swedish and Japanese standards among others. The industry has a good return of experience with oil tankers and an extensive list of areas prone to defects due to stress concentration and corrosion is given [1], [2], [3] and [9]. Nevertheless, it is well known that occurrence of corrosion and other defects might vary according to the shipyard design, fabrication standards, workmanship and the operation and maintenance procedures adopted during the trade period.

There are a number of differences and particularities inherent to each shipyard design, but one of the most important characteristics is the primary structure arrangement. Generally two main types of structural arrangement are noticed:

- Longitudinal ring stiffener system comprising deep girders within center and side tanks, supporting the transverse bulkheads horizontally stiffened.
  - There are no horizontal stringers.
- Horizontal system comprising in general four stringers within center and
side tanks, supporting the transverse bulkheads vertically stiffened. In general a longitudinal ring is provided in way of the center line girder. Fatigue was clearly not the main concern in the design of connections of primary and secondary elements for such type of vessels, but in some way, it was apparently compensated for the stiffer structural arrangement, larger corrosion margins and less use of HTS. During this period, oil tankers were built worldwide in different shipyards, some of them having poor fabrication quality.

III.2/ Vessels built after 1985

On the contrary of vessel built before 1985, the structure design of ships built after 1985 is optimized by means of finite element calculations and the extensive use of HTS to reduce the weight of steel. The hull structure design has used ST355, ST315 and ST235 steel types in different manners, in particular in the side shell plates, stiffeners and web frames. Some of them are built only using HTS in the cargo area. The use of HTS, in particular in the side shell area around the neutral axis, was found to be one of the main causes of problems associated to this type of vessel. Fatigue cracks of side shell longitudinal connections to transverse primary structures are probably the most typical defect of such designs, as fatigue strength of side shell longitudinals and corrosion margins are affected by the less stiff structural panels at bottom and side shell areas.

As a general rule, hulls built with ST355 should be specially regarded as such vessels have an extensive record of defects and likely have been reinforced with additional brackets after construction and before the second Class Renewal Survey. Another important parameter is the use of asymmetric profiles, i.e. angle stiffeners in the side shell and bottom panels. The use of angles at those locations having high probability of failure should be specially considered when evaluating hulls candidate to conversion, in particular when associated with use of steel ST315 and ST355.

| All in mild steel, typical unit built before 1985 | Almost every elements in high tensile steel, built after 1985. Special care should be taken to connections details of side longitudinal stiffeners. | High tensile steel in bottom and deck areas (around 90’s). Mild steel in neutral axis area (return of experience from first HTS hull designs). |

Table 2 - Material on typical midship sections of single hull units
IV. FPSO Hull Condition Assessment

There are approximately 197 s systems in operation or available worldwide, approximately 60% are converted from trading single hull tankers. These units have a service of already more than 20 years, where the two major threats for corrosion wastage and fatigue defects. Threats, which can be of different intensity depending of the units design, use and maintenance.

The following studies are in general the most common ways to assess the hull general condition:

- Structural analysis will determine the weak locations of the structure, taking into account the state of the vessel, and its future operations and site conditions.
  - Yielding and buckling analysis of the “as-is” state will allow determine minimum of steel renewal and reinforcement needed at conversion phase. Generally older ships have quite a margin on yielding and buckling criteria. However important corrosion can reduce significantly this margin, in particular on horizontal surfaces (web of side longitudinal stiffeners, horizontal stringers, bottom…).
  - Corroded FEM model. On a ship corrosion is everywhere. One tough question of repair work is to estimate which of the corroded element should be renewed and which should not. It is quite obvious when corrosion is above class society criteria. But when the corrosion is just below those criteria, the owner will decide if the plate/stiffeners should be kept - then the risk to have to change the plate because of excessive corrosion in the following years is important - or if the plate/stiffeners should be renewed at conversion - which guarantees to avoid to renew the plate for several years but is most costly. To fix the limit between renewal and not, it is common to perform structural assessment of the unit taking into account corrosion estimation at several stages of the unit service life – generally every 5 years. These calculations will give corrosion criteria for each element, depending of the loading of the structure. However these criteria are based on corrosion estimation, which are always quite critical since corrosion is a randomness phenomena. So it should not discharge of a good maintenance plan!

<table>
<thead>
<tr>
<th>200X</th>
<th>200X + 5 years</th>
<th>200X + 10 years</th>
</tr>
</thead>
</table>

Table 3 – Corroded finite elements models of aft centre tank and wing tank. Red elements show structural areas with don’t comply with classification rules in 2004, 2009 and 2014. The scantling of these 2 last years have been estimated based on several previous UTM report for this unit.
Fatigue analysis taking into account trading history of tanker and F(P)SO site will determine how many details should be reinforced to avoid cracks during the life of the unit. For both single hull types fatigue is a critical point (either because of bad details design, or because of the use of high tensile steel).

Figure 1 – Some typical fatigue fine meshes for a single unit.
Surveys will show if the ship is in good state from corrosion point of view. It will also reveal details and areas which are or had cracked or buckled. These areas should particularly be checked in the structural analysis, and adequate repairs should be put in place. The survey should also review the hot spot found during the structural analysis.

- Coating survey. A good ‘hard’ coating is a way to slow – if not to stop – corrosion. It can be efficiently used when structural assessment shows that corrosion margins are low. Generally ballast tanks (tanks which are used as ballast on the F(P)SOs but also which have been used as ballast during trading life) are fully coated. Cargo tanks are often coated on the lower and upper part. However any coating breakdown will allow corrosion process to take place and generally at a much more accelerated rate. So the effectiveness of coating has to be monitored throughout the unit service life by CVI and UTM (see section V.2.1/) in case of suspicion of breakdown.
- Wastage and feet of anodes should be surveyed, for replacement if necessary.
- Special care should be taken to the hull in way of the location where supply boats berth. If not protected, this area is a well know area of high risk of deformations due to collision.

Study of operation and maintenance of the trading ship. Old ships might have cargo tanks used for heavy ballast in the past. Those tanks are prone to excessive corrosion and should be especially checked. In maintenance reports, repetitive repairs of same type of details revealed that the details are not correctly design. A careful review of ship inspection and repair reports are necessary to detect this type of defects and to know at which frequency it generally breaks down. Structural analysis taking into account the site environment conditions will help defining the minimum necessary reinforcement

V. Maintenance

Deteriorations modes such as corrosion and fatigue are initiated during the tanker trading phase, more or less mitigated by conversion works and continued during all the F(P)SOs service life. Yet during the service life, dry-docking the ship for repair is generally not planned. The cost of dry-docking and of the unavailability of the units during the several weeks of route to dry-dock is prohibitive. That’s why when it is possible repairs are done on site, with minimum impact on production. These types of repair have their own constraints as shown in the following sections.
V.1/ Repair works on site

V.1.1/ Types of repair

The main types of repairs mentioned in this paper are:
- Coating
- Anodes replacement
- Re-welding of cracked welds
- Local inserts (for pitting and fatigue crack repairs)
- Renewal and/or fitting of structural elements (in case of global corrosion, or of reinforcement)

Temporary repairs, like crack arrestors holes, which are commonly used in shipping industry, should be considered with particular care in case of offshore facilities. The aim of crack arrestor holes is to stop the crack for a few months waiting for the next dry-dock. This is rarely the case for a station keeping unit.

If coating and anodes replacement can be considered as maintenance repairs, the three last ones almost always imply exceptional repair plan. They also imply hot works, which on an offshore unit is not a minor point.

V.1.2/ Hot works on a operating F(P)SO

Hot work on an F(P)SOs raises a lot of issues concerning the security of the people onboard and of the unit. The oil and particularly the vapor of the oil are highly inflammable. Available Guides or Rules are not adequate to repair of floating storage units on station. To cover this lack some companies follow the ISGOTT (International Safety Guide for Oil Tankers and Terminals), which applies to trading oil tanker and onshore terminals. The main issue about applying the ISGOTT is to condemn the tanks adjacent to the one within repair have to done. These tanks will have to be gas freed or inerted to avoid any ignition hazard.

The problem when closing several adjacent tanks is to know if the unit can be operated with these tanks empty. The following points should be investigated before any decision:
- Reduction of storage capacity
- Hull girder strength question. If the tank to be repaired is in midship area, maintaining empty adjacent tanks will create high hull girder bending moment and shear. These hull girder loads have to be assessed and checked below permissible values.
- Operating capacity of the unit if particular tanks are condemned (slop tanks, process tanks)
All these questions have to be answered on a case by case basis, depending on the general arrangement of the ship, tanks to remain empty and operating conditions of the unit.

Due to the difficulty to answer to all these questions, some operators have chosen to stop the unit during the repair work on site. In such case, depending on the field operation, shutdown may be avoided either by by-passing the oil directly to a shuttle tanker – the F(P)SO being used only for the process and pump room – or by leasing a station keeping floating unit for the duration of the repairs. Even in such case repairs might be done on site to avoid to disconnect, to unmoor and to tow the unit to an available dry-dock.

Instead of applying ISGOTT recommendations, some companies defined their own on-site repair guides. These guides are generally based on the location of hot works in tanks to define if adjacent tanks should be kept empty or not. They allow repairing...
far from the bulkheads at borders of tank without closing the adjacent tank. This limits the number of tanks unavailable during repair, but does not always solve all the issues listed above.

V.1.3/ Feasibility of repairs on site

Another question when doing repairs on site is the feasibility of these repairs and their quality. Some repairs are not or hardly feasible afloat, such as extensive repair of side shell, deck or bottom areas. There are some techniques using watertight boxes to weld inserts on a boundary with sea (bottom, side shell), however they require cutting of longitudinal plating and stiffeners contributing to the hull girder. Such discontinuities in the hull girder have to be carefully analyzed. The repair quality will also depend on the quality of alignment of the renewed elements. In such conditions – afloat with continuous incoming waves, in a confined space - respecting alignment tolerances is not an easy challenge, but is a critical point for elements contributing to the hull girder.

This is an extreme example of difficulty to repair on site, where a simple work in dry-dock can become a tough task afloat at all stages of the repair process. From cleaning process, which highly depend on water pump power and on capacity to treat dirty water up to the management of people onboard, where places are limited and security a first priority.

Preparation of a tank for repairs means cleaning, eventually removal of all the sediment and mud in way of repair areas, sufficient ventilation and lighting for the number of workers. In some countries, it can turn out quite difficult to remove the sediments of the unit, as disposal might not be accepted onshore. Another point is the work in confined space (see ref [5]), as ventilation, lighting, security exit will limit the number of people working at same time within the tanks. If huge teams of workers have been seen working almost 24h on some units, it requires a difficult and well done health and safety management plan.

The following paragraphs list the typical repair works cited in section V.1.1/, and for each mention problems that can be encounter in case of afloat repairs:

The quality of coating is essential. A bad coating might lead to quick breakdown and consequently to inefficient corrosion protection. Such areas may have an accelerated wastage. Three points are directly linked with the quality of coating:

- Qualification of worker and of the coat used. This point is independent of afloat or not repairs.
- Preparation of the surface. This point can be critical since to prepare the surface takes time, and time is not always available during repair plan, moreover in case of on site repairs.
- Atmosphere control. Humidity and temperature need to be controlled and maintained in acceptable values for the coating to correctly dry. If this is already difficult tasks in shipyards, it is even more difficult on board, with limited ventilation capacities, offshore natural humidity and oil and water temperature in adjacent tanks.

Changing anodes, by cold cutting and bolting or welding doesn’t raise particular problems. Special care should be taken with bolted anodes which are prone to loose contact by corrosion with the hull and thus become inefficient.
Fitting local insert for corrosion like pitting or cracked details raises the same question than the example of bottom plating renewal: possibility to cut the damage element, tolerance of alignment. The loading conditions chosen for the repair period, time should lower as much as possible deformations and stresses in way of the damaged detail. Else remove it, could become dangerous task and welding the insert in a highly stressed loading conditions can induced important residual stresses. In case of bad weather forecast after removal of the damaged detail, it should also always be possible to fit the new insert before harsh weather arrives. To renew whole parts of structure increases the alignment problems. In fact it is quite difficult to manipulate big pieces of steel inside the tank. This handling limitation is the main reason of why most of the repairs are done by several little inserts rather than by renewed once big piece of structure.

Finally the only way to avoid extensive and costly repair works is to have a full conversion, taking into account the expected life of the site, and to follow an efficient maintenance/inspection plan. This will be described in the two following sections.

<table>
<thead>
<tr>
<th>Defects</th>
<th>Location</th>
<th>solution</th>
<th>Defects</th>
<th>Location</th>
<th>solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitting</td>
<td>Bottom</td>
<td>Coated, if corrosion is acceptable.</td>
<td>Crack</td>
<td>Vertical stiffener connection to bottom longitudinal stiffeners</td>
<td>Insert, or re-weld if the crack is not through the plates.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Defects</th>
<th>Location</th>
<th>solution</th>
<th>Defects</th>
<th>Location</th>
<th>solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local corrosion (1 hole)</td>
<td>Web of side longitudinal stiffener</td>
<td>Inserts</td>
<td>Local corrosion (1 hole with leak)</td>
<td>Bulkhead</td>
<td>Inserts</td>
</tr>
</tbody>
</table>

Table 5 – Example of typical defects and their common repair solution
V.2/ Integrity management

V.2.1/ Inspection

To avoid costly and unexpected repairs during field life, a maintenance plan has to be put in place at the conversion stage. This maintenance plan should include a rational inspection plan, answering to the three main questions of inspections: when, what and how.

When inspect?
When inspect is really the first question to be answered. When compared with others offshore structure (like jacket or semi-submersible), F(P)SO hull structures have different function. The structure of a F(P)SO should support topside and accommodations (like the others), but also store products (oil, gas). This means that during inspections, one or several storage tanks will be unavailable. The unavailability of tanks is longer that the time of inspection, since the cargo tanks should be prepared for the inspection. The procedures to enter a tank (cleaning, gas freeing, stripping and ventilation for a tank of several thousand of cubic meters) take several days, depending on the cleaning and gas-freeing capacity of the unit. Thus the main constraint of inspection of F(P)SO structure is to avoid affecting the production and particularly the off-take schedule. Therefore inspections need to be planned early and to be well prepared, to avoid spending too much time in the tank and reduce the unavailability of the tanks.

The minimum inspection plan for a classed unit is the class society inspections. However with continuous survey notation, the owner can defined when each tanks should be inspected in the Rules interval. The inspection schedule is generally decided to minimize the impact of inspections in the operation of the unit. This schedule is likely to be modified depending on the results of inspections and on the maintenance and mitigation actions. It also bases on inspection loading conditions defined during the conversion project phase and approved by the class society. These loading conditions are defined to allow inspection of each tanks taking into account:

- the impact on the field operations
- Trim and stability check
- Strength assessment of the loading conditions (hull girder loads, local pressure on bottom, bulkheads)

Loading conditions to performed tank testing should also be considered.

On the back of defining when inspection are to be done, inspections plans should also include what should be inspected and how.

What inspect?
The scope of a class inspection of a F(P)SO is done on class requirements. These requirements depend on the type of tanks, on the age of the unit, on the previous inspections recommendations and on structural analysis reports which can identify potential critical areas. The inspections on hull structure don’t only include search for structural defects, but also for corrosion protection systems: coating and anodes. Generally ballast tanks
are fully coated and fitted with anodes. On the opposite cargo tanks are often not coating, or just the upper and lower part. Anodes should be looked at and wastage evaluated. Coating quality should be noted in the survey report. Breakdowns of coating often lead to accelerated corrosion in way of the breakdown. Thus they should be sought and state of steel below the coating breakdown should be assessed (by CVI, and if deemed necessary by UTM measurements).

**How inspect?**

Inspection methods are to be selected in accordance with the degradation mechanism expected and its respective type of defect. As said before, 2 mains degradation mechanisms affect the hull structure of FPSO:

- **Cracking**: fatigue cracks
- **Corrosion**: uniform and localized corrosion, pitting and grooving

A third type of damage can be found on the hull, but due to accident, not the aging of the structure:

- **Mechanical damage**: dents, contact and collision damages

The most common methods necessary to control the deterioration process are described here after:

1. **GVI** (General Visual Inspection) is used for determining the general condition of the tanks and spaces in order to identify deterioration of any component. In general, the GVI scope includes coating condition, rust staining and structural deformations of plating and associated stiffeners. When defects are suspected during a GVI, a CVI is done.

2. **CVI** (Close Visual Inspection) should be extended as deemed necessary, taking into account the maintenance of the tanks under survey, the condition of the corrosion prevention system and also where tanks have structural arrangements or details which have suffered defects in similar spaces or on similar ships according to available information. It requires good vision, good lighting and the knowledge of what to look for. The surveyor is to be within touching distance of the weld or component to be examined. CVI is used extensively to evaluate the condition or the quality of a weld or component. It is the primary evaluation method of many quality control programs. Therefore, when visual results indicate anomaly or defect, it is often enhanced by other methods of inspection which can identify defects that are not easily seen by the eye.

3. **Rafting** is a way to access to upper structures of cargo tanks. It consists to fill the tank with water little by little, while the inspection team is on a raft. It allows performing easily CVI or flaw detection on deck transverse or deck longitudinals. However rafting need water pumps to fill the tanks and water treatment capacities which are not always available on offshore units.

4. **CCTV** (close-circuit television) **associated with rope access** is another way to access to upper structures of cargo tanks. It consists of a team of climbers equipped with a camera and walkie-talkie. The climbers follow the instruction of the surveyor, which can survey the details of the upper structures on a TV. It avoids to fill the tanks with water, or to build scaffoldings.

5. **Flaw Detection techniques** are used to detect or confirm steel or weld defects, like cracks. Several methods exist, for different type of defects and with different preparation procedure and probability of detection. But for each of them it is critical to have well trained people to follow approved procedures and
to be able to analyze the results. The following list show the three main methods used on hull structure:

a) Eddy Current Inspection (EC)

b) Alternating Current Field Measurement (ACFM)

c) Magnetic Particle Inspection (MPI)

6. UTM (Ultrasonic Thickness measurement) uses sound waves of short wavelength and high frequency to detect flaws or measure material thickness. On the back of UTM asked by class societies, suspect areas should be subject to UTM as considered necessary by the Surveyor, therefore where wastage is evident or suspect it should be carried out. When thickness measurements indicate substantial corrosion, the number of thickness measurements is to be increased to determine the extent of substantial corrosion.

The above paragraphs described inspection methods of tanks. It can also be applied to deck and outside structures. However special inspections have to be carried out for the underwater structure and the ICCP system protecting the hull from corrosion.

7. IWS (In water survey) is required twice in a five-year period (maximum interval of 3 years) in lieu of dry-docking. In order to assure a continuing suitability of the cathodic protection system, it is recommended a condition monitoring routine based on such requirements. This requires the use of ROV or of divers (with CCTV system) to confirm the condition of the hull exterior. It often links with submarine inspection of mooring systems, risers and offloading hoses.

Diver inspection is required in order to examine the hull and the sea inlets. Sea chests should be opened and cleaned and valves checked.

It might be necessary to remove marine growth at some locations in order to examine the hull welds and coating condition. In case of marine growth cleaning is necessary, the work must be carried out carefully in order to avoid damage of the painting.

These inspections have no impact on the production. However the in-water survey is to be carried out with the ship at a suitable draught in calm water conditions; the in-water visibility is to be good and the hull below the waterline is to be sufficiently clean to permit proper examination. So the schedule of in water inspection is important and should take into account draft of the unit and typical weather at the period of the year when it is done.

ICCP system (Impressed Current Cathodic Protection) is an electronic system protecting the hull from corrosion by maintaining an electric potential between hull and sea water. The assessment of the efficiency of the ICCP system is performed by measuring the steel to sea water potential and inspecting the cathodic potential equipment. Measurements and inspections are necessary for:

- Checking that protection has been achieved according to design criteria and that each part of the cathodic protection system is operating properly;
- Detecting performance changes of the ICCP system because of working conditions variations with time.

It is to be noted that changes in the ICCP system to maintain protection are necessary to meet changes with time of conditions which affect protection.
An inspection plan has to include when each of these methods should be used; in order to have the tools and the team (for flaw detection techniques, or CCTV) available during the survey.

As part of the inspection, tank testing should be performed for tanks which are intended to contain water or oil. It consists in filling tanks up to the upper boundary of the tank, and inspecting boundaries to insure that no leak or deformations appeared.

<table>
<thead>
<tr>
<th>Locations</th>
<th>Age of unit (in years at time of class renewal survey)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Web frames</strong>&lt;br&gt;One web frame ring, in a wing ballast tank, if any, or a wing crude oil storage tank used primarily for water ballast (1)</td>
<td>5 &lt; age &lt; 10&lt;br&gt;All web frame rings, in a wing ballast tank, if any, or a wing crude oil storage tank used primarily for water ballast (1)</td>
</tr>
<tr>
<td><strong>Deck transverses</strong>&lt;br&gt;One deck transverse, in a crude oil storage tank (2)</td>
<td>One deck transverse (2):&lt;br&gt;- in each remaining ballast tank&lt;br&gt;- in a crude oil storage wing tank&lt;br&gt;- in two crude oil storage centre tanks</td>
</tr>
<tr>
<td><strong>Transverse bulkheads</strong>&lt;br&gt;One transverse bulkhead in a ballast tank (4)&lt;br&gt;One transverse bulkhead in a crude oil storage wing tank (4)&lt;br&gt;One transverse bulkhead in a crude oil storage centre tank (4)</td>
<td>Both transverse bulkheads, in a wing ballast tank, if any, or a crude oil storage wing tank used primarily for water ballast (3)&lt;br&gt;One transverse bulkhead in each remaining ballast tank (4)&lt;br&gt;One transverse bulkhead in a crude oil storage wing tank (4)&lt;br&gt;One transverse bulkhead in two crude oil storage centre tanks (4)</td>
</tr>
</tbody>
</table>

Table 6 – Example of extension of CVI for a class renewal survey of single hull converted to fixed unit. (Extracts from the ref [8])
Tank testing requires a procedure to be able to inspect each mandatory boundary in the Rules interval.

<table>
<thead>
<tr>
<th>Age of the unit in years</th>
<th>All ballast tank boundaries</th>
<th>Cargo tank boundaries facing void spaces, pipe tunnels, representative fuel oil tanks, pump rooms or cofferdams</th>
<th>All cargo tank bulkheads which form the boundaries of segregated cargoes</th>
</tr>
</thead>
<tbody>
<tr>
<td>age \leq 5</td>
<td>All ballast tank boundaries</td>
<td>Cargo tank boundaries facing void spaces, pipe tunnels, representative fuel oil tanks, pump rooms or cofferdams</td>
<td>All remaining cargo tank bulkheads</td>
</tr>
<tr>
<td>5 &lt; age \leq 10</td>
<td>All ballast tank boundaries</td>
<td>Cargo tank boundaries facing void spaces, pipe tunnels, representative fuel oil tanks, pump rooms or cofferdams</td>
<td>All remaining cargo tank bulkheads</td>
</tr>
<tr>
<td>10 &lt; age \leq 15</td>
<td>All ballast tank boundaries</td>
<td>Cargo tank boundaries facing void spaces, pipe tunnels, representative fuel oil tanks, pump rooms or cofferdams</td>
<td>All remaining cargo tank bulkheads</td>
</tr>
<tr>
<td>age &gt; 15</td>
<td>All ballast tank boundaries</td>
<td>Cargo tank boundaries facing void spaces, pipe tunnels, representative fuel oil tanks, pump rooms or cofferdams</td>
<td>All remaining cargo tank bulkheads</td>
</tr>
</tbody>
</table>

**Table 7** – Example of tank testing requirements from Bureau Veritas Rules

For such a complex project than a whole F(P)SO complete knowledge of inspections methodologies and “how-to” are quite difficult to achieve. That is why on several projects document is built which regroup all the information necessary to schedule, follow and archive inspections of the unit, whatever the reasons of the inspection – class requirements for the hull, builder specifications for particular parts of moorings and piping, company specifications if any.

In order to optimize inspection in term of time spent (i.e. cost of inspection) and of efficiency of inspection (i.e. probability of detecting default) Risk Based Inspection (RBI) plan can be used. RBI will study the risk linked to each details of the structure and determine when and how it should be inspected to get acceptable low risk. So it will specify the frequency of inspection of each tank, the details that should be inspected in each tank and the mean of inspection. This plan, if approved by class society, can replace the Rules mandatory inspections.

**V.2.2/ Maintenance**

As consequence of inspections, maintenance actions might be required. The aim of a maintenance action is to maintain the structure in a good enough state to avoid unexpected and costly repairs. Maintenance actions are generally quite short and light actions that do not need to be planned long time in advance. The main maintenance actions are:
- Cleaning (mainly for inspections purpose)
- Retouching of coating where it breakdowns. This point is very important, since very often corrosion is much quicker when it takes place in coating breakdown.
- Mitigation procedures or coating of very localized corrosion
- Replacement of anodes
- Etc...

The same difficulties are encountered for these maintenance actions than for the repair on site. To limit the unavailability of the tanks, it is possible to keep the tools (coating for example) to perform minor maintenance on board during the inspection.
However maintenance of a F(P)SO is not limited to actions on structure. It also regroups all kind of actions that insure integrity of the unit in all eventualities. In maintenance tasks we can also add such things as:

- Keep a traceability of every defects, recommendations, maintenance actions or repairs made on the unit before and after the conversion. This is quite a big challenge, since it represents a lot of documents and of different interveners:
  - as-built drawings,
  - conversion drawings, inspections reports, shipyard reports
  - Class reports, UTM reports, owner reports concerning operations, actions, accidents etc...

When it comes to define inspection or repair plans, this kind of information are really important and help to focus the work directly at the most critical areas. It also helps understandings which kind of default is in question (design error, operations error, accident) and thus gives a quick and appropriate answer.

- Choose the loading conditions with marine knowledge (avoid alternate loading conditions to limit hull girder loads, let the ballast tanks filled as long as possible for the anodes to be as efficient as possible).
- Keep records of eventual collision (with supply boat for example)

New tools are now being developed and implemented to help owner maintaining the unit. Generally they are Internet-based softwares which allow authorized people to access to whole or part of information everywhere around the world. Access and update of the database is then possible from head office of the company, from local offices or from board if Internet is available.

![Figure 2 – Examples of screens of web tools storing and organizing inspection, maintenance and repairs history of a FPSO.](image-url)
They store all kind of information, from as-built drawings, to pictures of the latest inspection, including classification reports and certificates. They are organized specifically for each unit, with access to each tank and areas of the unit information by clicking on the unit general arrangement.

VI. Conclusion

Converted single hull units are now a great challenge regarding inspection, maintenance and repairs. The last years have revealed how repairs on site are difficult and costly; but they have also helped defining guidance and practice for offshore repairs, despite the difficulty to conceal hot works on oil storage unit, security, and operations.

Maintenance and inspection of units are known as the best way to avoid unexpected repairs after the conversion. They are being optimized in term of efficiency and of reducing impact on operations through documents which regroup all the rules and guidance requirements and through RBI inspection plans.

Web tools are also developed to store, class and share to all the concerned people all kind of information concerning the unit (maintenance actions, inspection plans, drawings, pictures), and this worldwide and instantaneously.

Finally the key of the success of the challenge of maintenance and inspection is in the preparation of inspection and maintenance plan based on strong and shared knowledge and understanding of the unit and of her history.

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VIII. References