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Understanding Through Experience – Key Findings From the FPSO Structural Performance Joint Industry Project

C. Serratella, ABS Consulting Inc., and R. Spong, Energo Engineering, Inc.

Abstract

The Structural Performance Joint Industry Project (JIP) was initiated to enhance the current understanding and decision making capability for future project teams or current integrity management groups working for operating companies and responsible for managing hull structural integrity for FPSO/FSO type assets. The JIP has collected a comprehensive set of corrosion data, observed fatigue damage as well as coating and repair performance for 10 FPSOs and FSOs currently in operation throughout the world. Geographic regions covered by this representative set of units include the North Sea, West Africa, South America and Asia. While there have been other queries and participant survey type data collection efforts for floating production units, this JIP represents the first wide-ranging and detailed collection and evaluation of FPSO/FSO performance data from the various regions of the world , operating companies as well as for new and converted vessels. Of equal importance, the research has gathered lessons learned and success stories obtained from a review of vessel operations, maintenance/inspection, and repair records as well as interviews with the personnel who know best; the operations staff. In order to better understand hull structural performance, vessel operational data including design and observed environmental conditions, tank loading sequences and service conditions, were also obtained. This information has provided valuable insight into possible factors influencing the structural performance.

This paper presents a brief overview of the project as well as key findings from the collection end evaluation work. Specifically, the paper reports on findings in the following areas:

- Description of different hull integrity management approaches
- Observation of most prevalent corrosion and fatigue integrity issues faced by operators today
- Investigation into contributing factors impacting hull integrity
- Advice on key items to address during conversion or new construction of FPSO/FSO's

FPSO/FSO operators safely and effectively manage hull structural integrity, generally with minimal impact to operations. However, there is ample evidence from the JIP collection and evaluation effort that hull integrity problems do occur and require actions to be taken covering additional inspection, monitoring, or repair. Most of these decisions are required to be made on-site with minimal or no impact to production, but it can be costly, time consuming and difficult to manage. The JIP provides insight into the preventative measures that have the most impact on these types of problems. The collected experience-based data will facilitate the development of rationalized approaches to the decision-making regarding FPSO design, and inspection.

Introduction

The popularity of the FPSO/FSO offshore facility is evident in the ever increasing number of operating units and future planned units. As of mid-2004, there were approximately 97 FPSOs operating around the world with another 19 under construction [1]. Furthermore, there are numerous other FPSO/FSO facilities planned or under study for future field developments. Of this fleet of FPSOs, the majority of the vessels are converted from trading tankers, primarily older vintage single hull tankers, but there is an increasing trend for new build FPSOs as tanker conversion candidates become more difficult to obtain.

Although there is considerable growth for these types of facilities, it is generally recognized that when compared to trading tankers, FPSO/FSOs have very limited experience from which to draw historical data and trends. This is particularly true with regards to the long-term hull structural performance. For tankers, there are many vessels that have 20-30 years operating experience and as such the experience is used to identify and address structural integrity issues, both by preventative methods or in response to observed problems that occur during operations. In contrast, most of the FPSO/FSO installations have been in operation for less than 10 years and as a result there tends to be a lack of experienced based data from this specific service that can be used for decision making during design, conversion/construction for overall management of the hull structure. Additionally, the offshore oil and gas industry is drawing upon the lead set by other industries (e.g., nuclear, aircraft, etc.) via the application of risk-based approaches in both design and inspection. However, in order to apply risk-based methods, experienced based data related to corrosion, corrosion protection, fatigue performance as well as an understanding of how operating parameters impact these parameters is needed to successfully apply these methods.

Recognizing these current limitations, the FPSO Structural Performance JIP was initiated with the objective of aggressive data collection and evaluation of experienced based FPSO performance structured to enhance current understanding and decision-making capability related to structural integrity management of the hull. In order to accomplish this, the following success factors were needed;

1) Support from FPSO industry leaders.
2) Access to FPSO/FSO vessel class survey reports, 3rd party inspection and repair records, and operations data.
3) A method that enabled the JIP team to obtain comprehensive detail on vessel inspections and operations without taxing the resources of the vessel's support and operations staff.
4) Access to key anecdotal information from the vessel operations staff to flush out the data reviewed in items 2 and 3 listed above.

For this project, the JIP team has been fortunate to be successful on all four of the above requirements. Support and participation in this project came from seven key operating companies which own, operate, or have interest in a large percentage of FPSO/FSOs operating throughout the world. The seven JIP participants include BP, ConocoPhillips, ChevronTexaco, ExxonMobil, Petrobras, Shell and Single Buoy Mooring (SBM). Each company recognized the need for this effort as well as the benefits that come from the project both within their own organizations and in sharing with the other companies participating in this JIP.

With the participation of the aforementioned operators, access to the required vessel data and key individually responsible for maintaining this information could be obtained. It is important to note that the value of the data collection effort is directly related to the details that could be collected on the vessel's hull integrity. Hence, the use of questionnaires to obtain data was avoided. Instead the data was obtained through review of all available Class survey reports as well as owner operations and inspection records, and maintenance and repair (IMR) files on the hull. This entailed one or two engineers visiting the operating unit where the vessel files resided and reviewing all relevant documents on site (e.g., design reports and analyses, inspection and repair reports, special studies and analyses, etc.).

The method used in the JIP to collect the data involved a three step process.

1) Step 1 involved the review of available class survey and gauging files, if the vessel was classed. This information provided information that could be used to investigate corrosion rates as well as obtain a general understanding of the vessel's history while in service as a FPSO/FSO, and for conversions, also covers the history while in tanker service.
2) Step 2 involved the review of the owner's files. This information supplemented the class files providing more detail on the inspection findings and repairs as well as impact to operations (financial, downtime, production loss, etc…). Additionally, the operators' maintenance and inspection philosophy, vessel operation parameters (e.g., loading regime/sequence, cargo temperature, tank service and deviations from planned, etc.) were also obtained from the owner's files.
3) The third step, which effectively closes the data collection loop, was vessel operations input. In this step, the JIP team met with operations staff to review observations from the class and owners files, filling in gaps where information might be missing as well as confirming conclusions related to integrity problems observed in the files. Additionally, the meetings with the operations staff provided insight into how maintenance and vessel operations were adjusted or modified to address arising integrity issues. The meetings provide historical and anecdotal information that helps put the observations in perspective within the management of the entire FPSO/FSO asset.

This collection process was conducted on 10 vessels which were selected by the participants from a pool of approximately 18 candidates which the participants own, operate or have invested interest. The general requirements for a candidate vessel were that the vessel has been in operation as an FPSO/FSO for over five years. This ensured that at least one comprehensive survey, typically one Class required special, would have been conducted on the vessel. During the selection process, an effort was made to select from the pool of vessels such that there was a good cross section of the current worldwide fleet. The make up of the 10 vessels was as follows:

- Operating region:
  - Brazil - 2
  - West Africa - 3
  - N. Sea/N. Atlantic - 3
  - Asia/ Australia - 2
- Construction
  - New build (All double sided hulls) - 3
  - Conversion (All single hull, early 1970s vintage) - 7
- Operations
  - FPSO - 7
  - FSO - 3

Another important aspect related to the vessels is the number of years in operation as an FPSO/FSO. The majority of the vessels (7 total) have been operating between 6-8 years. Of the remaining three vessels, two have been in service for 11 years and one for over 23 years.

As shown above, the 10 vessels make up a very representative cross-section of the current fleet.

Key Aspects of the FPSO Structural Performance JIP

The JIP focused on the following key topics:

- Understand the Integrity Management philosophy of the Operating Unit responsible for hull integrity
- Perform a comprehensive study of FPSO/FSO specific hull corrosion rates, with results compared to typical tanker rates observed in similar service via published source data
- Perform a qualitative investigation into coating performance
- Document fatigue performance of the hull structure
- Document all corrosion, fatigue, operational problems and success stories, and anecdotal findings into a comprehensive searchable "Lessons Learned Database"

The remaining sections of this paper will briefly discuss some of the key findings and observations.

Integrity Management Philosophies

The operating companies have similar but varying philosophies in terms of managing the integrity of the hull structures.

With regard to staffing, depending on the size of the operating company, the integrity management program may be run by a small in-house team of operating company employees who form the inspection and maintenance (IM) support. In addition to the FSO/FPSO's, these teams also support other key in-field assets such as fixed platforms and subsea production. In most instances, the operating unit will draw upon an in-house central engineering resource to support the activity, if assessment of the results is needed for the IM plan execution. Other companies utilize an in-house representative as a focal point who then subcontracts key aspects of the inspection, data management and engineering support via third party contracts.

Another major difference lies in the culture upon which the operating company manages its FSO/FPSO's. Two distinct cultures are prevalent; one that derives influences from a shipping/marine background and another that derives from an upstream oil and gas background. Often the marine/shipping influenced team relies heavily on the Class Society to outline the requirements for inspection and integrity management of the unit. In this case, typically very little is done beyond the requirement laid out within the Class rules (i.e. a standard 5 year cycle of inspections coupled with periodic gaugings of representative structures). In this instance however, the IM team often has vast tanker experience to draw upon and this assists in proper management of the hull. In the case of the oil and gas influenced programs, the IM plan for the hull will usually be an asset-specific plan (often the unit may not be classed or remain in class). The plan will outline a schedule of inspection for the various hull compartments backed up by detailed work scopes for each inspection. In this case, the plan is performance-based, often drawing upon risk assessment methods to focus and optimize the IM program. Often, this team is less experienced in tanker operations, but does have experience in the operation of offshore facilities (fixed or floating).

Cargo Tank Corrosion Rate Evaluation

The next key task of the JIP was the collection and evaluation of available thickness measurements (gauging) conducted during the in-service inspections. This information was used to develop corrosion rate estimates in various tanks and locations from the 10 vessels, thus providing a large data set of FPSO/FSO specific corrosion data. This information can be used to compare between vessels to investigate difference in service conditions and associated impact on rates as well as between published guidelines such as the Tanker Structural Cooperative Forum (TSCF) [2].

The corrosion rate estimates for new build vessels were generally a straightforward exercise, in which the gauged thickness is subtracted from the as-built thickness and divided by the years in service.

For the conversions, the process is more involved. First the regions of the hull that were gauged during the conversion are mapped. These locations are compared to the regions of the hull that were gauged during later in-service inspections. Where there is overlap in the inspections, for example the same transverse web frame or the same region of deck plate, the specific gauging points on the components are examined to determine if there are "coincident" points. Figure 1 shows a diagram portraying the general process. Note that "coincident" in the case of gauging points should not be taken in the literal sense of the word. Generally, "coincident" is considered gauging points that are within one meter of one another. It is recognized that one will never obtain exactly "coincident" gauging points, but since the objective is to estimate the general corrosion rate, on average the measured material loss between the individual points should provide a representative portrait of the corrosion within the tank for the particular component of interest. For this approach, one corrosion rate "data point" generally equates to two "coincident" gauging points. To place the effort in perspective, a typical corrosion rate data set for a single vessel is between 300-1800 "data points".

It should also be noted that for some components such as deck and bottom plating, the averages for individual plates are used instead of individual gauging points. This is also shown pictorially in Figure 1.

When working with thickness measurements, there are obviously inherent errors that present themselves. In some cases, there were instances where the original or conversion thickness is less than the later in-service measurement at a "coincident" point. Whether to discard these points all together or count these data points as "0" corrosion and the potential impact to the corrosion rate estimates was investigated. The results of the sensitivity studies indicate that for a component on a conversion with 20 or more data points, treating data points with measured increases in the range of 0.1-0.25mm as "0 mm", results in corrosion rate estimates between 0-15% lower than if all data points with measured increases were discarded. In cases where there are less than 20 data points for a conversion component, the estimated corrosion rate can be 15-30% more than if all data points with measured increases are discarded. When reviewing the data on a new build which had a large overall gauging data set, the percent difference in the estimated rates appear to be considerably higher. In this case, there were many gaugings greater than the design original thickness. This may indicate a bias for new builds possibly due to over tolerance on the as-built plate thickness. Based on these sensitivity studies, it was decided that all data points that produce a wastage less than 0 would be discarded.

The process provides a very comprehensive set of

FPSO/FSO specific corrosion rates for the different structural components (e.g., web frames, bottom plate, etc.) and corrosion protection system. Moreover, the tank service conditions, to include cargo temperatures, produced water in cargo tanks, offloading frequencies, crude weight and sulfur content, etc., can be coupled with the corrosion rate results to investigate differences between the 10 different vessels as well as published data such the TSCF.

The following bullets provide an overview of the results of the cargo oil tank corrosion rate evaluations for various internal structural elements. The rates are not presented in detail due to the project's confidentially commitments, but instead described in relation to the published TSCF corrosion rates, which are widely used as the industry guide for FPSO/FSO design for forecasting conversion renewal requirements or new construction material wastage margins.

- *Uncoated Deckhead Elements (deck plating, deck longitudinal web and flanges)* - The calculated corrosion rates were generally found to be in the mid to upper range of the TSCF rates.
- *Uncoated Bottom Elements (bottom plating, bottom longitudinal web and flanges)* - Two vessels had uncoated bottom elements. Between the two vessels there was a large discrepancy between the corrosion rates, with one vessel showing rates in the upper range of the TSCF rates and the other on the lower range of the TSCF numbers for these elements. When reviewing the tank service conditions for potential contributing factors, there were three variables that were notably different, offloading frequency, temperature and crude sulfur content (i.e., sour or sweet crude). The vessel with the higher corrosion rate had significantly lower offloading frequencies (upward of 3 months) compared to an offloading frequency of approximately one week for the vessel with the lower rates (i.e. dwell time of the cargo within the tanks). The typical amount of produced water in the tanks that had to be decanted during each offloading cycle was similar between the two vessels. However, factors that would normally be attributed to higher corrosion rates such as higher crude temperatures and sour crude were present on the vessel with the lower rate. Based on these tank service condition differences, it tends to point to the duration (i.e., offloading frequency) for which the "undisturbed" oil and associated settle water resides on the bottom structure being one of the main contributors in the variation in the rates.
- *Coated Bottom Elements* - For coated bottoms, the calculated rates, which are assumed to be thickness measurements taken at regions in coating break down area, were comparable to the TSCF general corrosion rate for uncoated bottom plating. This is based on a comparison of rates from four vessels in the collection effort. Note that in all but one of the vessels, anodes were present as back-up to the coatings.
- *Uncoated Side Shell Elements (side shell plating, side shell longitudinal web and flanges)* - For the shell plating, the general rates tend to be higher than the TSCF rates based on data from four vessels. Based on a review of the tank service conditions, all four vessels have light sweet crude and the temperatures are not generally in the high range. It is unclear why the elements in this region tend to be on average higher than the TSCF numbers.
- *Uncoated Longitudinal Bulkhead (LBH) Elements (LBH plating, LBH longitudinal web and flanges)* - For the LBH elements, the calculated rates tend to fall on the upper end of the TSCF guidelines, with the exception of one of the vessels. When comparing the differences between the service conditions for this vessel and the others, it is noted that the base sediment and water (BS&W) is lower and the crude is generally heavier than the other vessels. Additionally, it was observed that the vessel found to have the highest corrosion rate had the longest duration between cargo offloading and there were a number of cargo tanks that were not normally used. These factors may indicate that the rates are partially dependent on the surfaces being coated with oil that provides a protective coating to the bare steel (provided the crude is clean and not very hot). Shorter offloading frequencies and heavier, clean oil tending to keep these surfaces coated.
- *Uncoated Transverse Web Frame Elements (web plating, and ring face plates)* – The transverse web frame plating rates were generally in line with or lower than the published TSCF rates based on thickness readings from six of the vessels.

Obviously, care must be taken prior to blindly applying the above generalized rate comparisons. Inevitably, there are limitations as well as potential bias that can influence the thickness reading data set (e.g., limited gauging point locations for different tank services, accuracy of thickness readings, etc.). However, even with these potential deficiencies, the rate study provides an excellent starting point for better understanding the FPSO/FSO specific service conditions and the impact these conditions have on corrosion rates. Furthermore, due to the various factors influencing the corrosion rates and spread within the data, looking at the data as a generalized whole has less merit than when used to investigate differences between the individual or groups of vessels. When used in this capacity, the calculated rates can be looked at on an individual basis or binned into groups based on the service condition parameters. This enables those making design decisions on appropriate corrosion margins and/or renewals for conversions to compare their particular vessel and the anticipated service conditions to these observed rates.

Lessons Learned Database

One other product of the JIP is a "lessons learned" database that provides in-detail hull integrity issues encountered while in service. For each integrity issue or "finding" the following details are provided:

- Description of finding (i.e., location, extent of damage, etc.)
- How problems or issue was identified (e.g., scheduled inspections, monitoring program, accident, etc.)
- Perceived causes of problem. This is based on inspection narratives, special studies and/or conversations with operations personnel.
- Response to integrity problem (e.g., repair details, changes to maintenance or inspection program, operations changes such as changes to loading patterns, etc.)

- Impact to operations and repair effort (e.g., man-hours and/or cost when available)
- Summary of the lesson learned. This generally highlights measures that may have prevented the problem.

Figure 2 shows an example of the findings database sheet. In addition to this information, the database also contains information on the vessel particulars (e.g., displacement, dimension, tank arrangement, history, tank usage and protection systems and operating parameters (i.e., observed on site environmental conditions and motions), cargo information such as temperature, offloading frequencies as well as typical tank loading sequences.

The remaining sections of this paper provide an overview of key findings as well as the perceived instigating factors observed in the development of the lessons learned database.

Corrosion Damage and Repair

When reviewing the FPSO/FSO service years of the vessel in the collection effort, the majority of the units have only been in service on average for 7 years. This is a relatively short service time for corrosion issues to occur, since this is a deterioration mechanism whereby if adequate protection (coatings) and backup systems (anodes, etc…) are provided in the design, these issues should not manifest themselves at all in this period of time. If they do, it should be much later in the service life. However, the data tends to indicate that even early in the service life, regardless if it is a new build or conversion, corrosion problems can arise quickly, potentially resulting in significant damage that warrants in-service repairs. Furthermore, there are a number of instances where extensive localized corrosion has occurred in locations, such as void and machinery spaces. Table 1 provides descriptions of select corrosion related integrity issues that were observed. The intent of the table is to provide general insight into the typical integrity issues that can arise offshore as well as some of the perceived contributing factors.

When reviewing the select observations in the table, there are general themes related to prevention that present themselves from the table. These are described briefly below.

- *Importance of Inspection and Maintenance of Void/Machinery Spaces* – The first three observations reinforce the need to adequately inspect void and machinery spaces particularly those locations that may be exposed to seawater leak sources, or sludge or oily water, such as found in bilge spaces. For finding 3 in the table, monitoring or periodic checks of voids to confirm no standing water is present may have prevented the extent of corrosion.
- *Importance of Baselining the Hull Structure* – For findings 3 and 5, thorough baselining of the hull structure ensures that the overall condition is known and most importantly documented, such that areas in need of renewal are caught while in the shipyard and areas that are acceptable but known to have pre-existing corrosion or issues can be monitored over the life of the asset. Baselining should include a thorough review of the vessels integrity history to identify prior problems areas. It should also include an "expanded" inspection program prior to the shipyard conversion, including extensive thickness measurements and close visual as well as non-destructive examination, as deemed necessary. The term "expanded" is intended to represent inspections that are in addition to the normal minimal Class requirements for a special survey. Thorough baselining provides the foundation for all subsequent inspections carried out over the in-service life as well as the necessary understanding of the hull integrity issues for the specific facility.
- *Design Assumptions* – Ensuring the corrosion protection design assumptions are appropriate for the intended service conditions are highlighted in finding 4. Reception and dedicated settling tanks are normally under more severe service conditions, making them more susceptible to coating breakdown, anode depletion and ultimately corrosion. Usually these tanks will be exposed to higher fluid temperatures, more produced water and increased overall throughput than a typical cargo tank and thus the protection measures must be adequately designed to accommodate these conditions. It would also seem wise for the IM team to revisit the design assumptions made for these protection systems with the operating crew on board the vessel 1 or 2 years down the road from commissioning to ensure initial assumptions were in fact correct.
- *Management of Change* – Operational and field requirements of the vessel will inevitably change as the field ages. Whether it is more produced water running through the tanks, changes in the sulfur content or lower production rates, all result in changes that may detrimentally impact the hull integrity. Findings 4 and 5 tend to highlight this. In these cases, the tanks that sustained corrosion damage were under service conditions that changed overtime. For finding 4, the operating temperatures and sulfur content were higher and for finding 5 the tanks were more or less unused with standing fluids in a hot humid environment. Recognizing these changes, the potential impact to the hull integrity and timely acting upon them can mitigate problems before they require costly repairs. Generally, action may be a tank inspection, possibly at reduced interval to verify corrosion protection measures are adequate or confirm the conditions in the tanks are not precipitating an undesirable condition.

Fatigue Damage

Another key deliverable of the JIP was the collection and evaluation of fatigue damage that has been found on the candidate FPSO/FSO hulls. The objective was to document fatigue related findings such as repetitive cracks and fractures within the hull if they exist and also if they do not. That is, good fatigue performance is also documented as an example for future project teams to draw upon. One-off type cracks and damages were not recorded as part of this section of the work, but larger fractures if caused by accident damage or a similar event, are covered in the Lessons Learned Database.

No attempt was made by the JIP team to categorize or determine the root cause of the fractures. The participants felt that the variables at work and the amount of conjecture to accurately predict a root cause for the damage would lead to incorrect assumptions and conclusions. In this regard, only objective evidence, provided in the form or metocean data, vessel response (design and observed), tank cargo load/offload and ballasting regimes and frequencies was documented. A typical table showing the layout of the data collected is shown in Figure 3. Also provided in a separate section of the JIP work are pertinent design details related to construction details for critical welds and connections, materials of construction, and general arrangements of the hull structure are provided for the participants to draw their own conclusions.

When cracks and damage were found, the work attempted to document corrective actions taken to address the problem, covering enhanced monitoring of cracking or repairs affected. For conversions, the findings also document any actions taken at conversions (such as NDE to find existing damage or retrofit/modification of details) to prevent damage as an FPSO/FSO.

Crack counts and observed locations are provided on idealized vessel diagrams for each type of repetitive problem encountered. Also documented was information on when the cracks were found and if they had also previously occurred during operations as a tanker (if a conversion). It is hoped that when one couples this type of information with the observed loading on the vessel, patterns or root-causes associated with the fractures will become apparent for the JIP report users. Additionally, designers can use the information to compare their particular vessel (new build or conversion) to this data to ensure adequate attention is being applied to regions where fatigue related problems and associated detail have occurred in the past.

When reviewing the select observations within the fatigue summaries, the following general themes would seem to be the main causes of FPSO/FSO related fatigue problems:

- ❖ *Connection Details:* Often, a particular vessel used in a conversion was fatigue prone as a tanker and this problem carries through as a converted FPSO/FSO. The age of the vessel and the construction details prevalent in some conversion candidates were not as fatigue friendly as present day tanker connection details. Most often these types of fractures are associated with the nuisance type cracking typically found in longitudinal connections along the side shell, LBH, deck and bottom. Nevertheless, they must be dealt with and managed as part of the IM program when found, especially in larger numbers.
- ❖ *Under- or Over- Estimation of Loading:* Occurs in both new builds and conversions. The vessel may be experiencing fatigue problems in situ due to an underestimation of the environmental loading or tank loading regimes, or a combination of both. Problems of this type have been found, both isolated to a specific area of the hull or as widespread damage.
- ❖ *Workmanship:* In some instances related to conversions, the cause of cracking can be ascertained as due to poor welding quality during construction which given the extended life of the vessels as FPSO/FSO's, manifests itself in the form of fatigue related problems as the vessel ages. The reduced life associated with poor weld quality is not something typically accounted for in the fatigue calculations performed during the conversion project. This could lead to overestimation of remaining life in actual service.
- ❖ *New Locations and Areas for Fatigue Damage:* Again, in some conversion candidates, the cargo loading regimes introduce the vessel to new forms of cyclic loading often on bulkheads and components not originally designed for such loads at the frequencies experience on FSO/FPSO's. While robust for strength purposes, certain design details were not meant to see loading of this type at the frequencies typically seen in floating installations (often 3 to 7 day parcel offtakes and loading).

Once again, to reinforce the findings related to corrosion above, it would seem that for conversion candidates, a NDE-based sampling plan covering fatigue critical locations would seem warranted in addition to gauging which is normally performed. The collected data would seem to indicate that the cost of obtaining this information in the shipyard is approximately 8 times cheaper than having to obtain this information in situ. Having accurate baseline data for fatigue prone locations obtained in the shipyard during conversion (or even for new-builds) lays the foundation for integrity management decisions in the future. This information is also necessary to assist in providing the necessary data to develop more advanced integrity management planning, such as risk and reliability based programs, which enable the operator to optimize their hull IM programs.

Conclusions

Key observations and conclusions that can be drawn from the JIP effort show that while there are many similarities between FPSO/FSO's and tankers, there also exist unique factors which must be considered for each installation on a case-by-case basis. The JIP provides unique insight into the integrity issues related to FPSO/FSO facilities. It is important to mention that, in all cases, the issues gathered during the JIP were successfully managed offshore by the operators. The data provides comprehensive information on a variety of issues that readily reinforce what is generally understood by the operators. In this case these understandings are not typically presented as a whole since they tend to be observed by one asset team or another in different locations around the world and operated by different companies. The JIP closes these gaps across distance and company lines and enables a more holistic understanding of hull integrity issues.

It is anticipated that data collected from the JIP effort can be used by the participants to aid them in developing and further refining future project design specifications related to hull structures. Areas anticipated as possibly being aided by this JIP effort include but are not limited to the following:

- ❖ *Hull Vetting for Conversions* – It is anticipated that project specifications will be enhanced to cover the possible need for enhanced gauging and baseline inspection of fatigue critical locations so this information is available as needed during the vessels operating life as an FPSO/FSO.
- ❖ *Design Assumptions:* This covers improvements to design aspects covering topics such as proper selection of environmental loading, tank loading and service influences on strength, fatigue and stability, hull

and process deck interface issues, coating and anode design assumptions, etc….

- *Operational and Ergonomic Aspects:* Covers specification improvements related to access and ease of inspection (especially when considering site environmental conditions), fabric maintenance schemes for painting, coatings, supply boat damage contingencies, equipment and consumable handling at site, etc.

Future Work

This paper covers data and evaluation efforts conducted as Phase 1 of the JIP. As other participants join, it is hoped that the effort can be extended to additional candidate vessels further expanding the data set. Additionally, plans for a future phase to this project is a Hull Integrity User's Group, whereby the JIP participants meet annually, where additional lessons and observations on these and other vessels are included, updated and shared, with the goal of continuously improving FPSO/FSO hull performance.

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2. TSCF (1997). Guidance Manual for Tanker Structures, Tanker Structure Co-operative Forum, Witherby & Co. Ltd.

Figure 1: Typical Gauging Data Points Used for Corrosion Rate Estimates

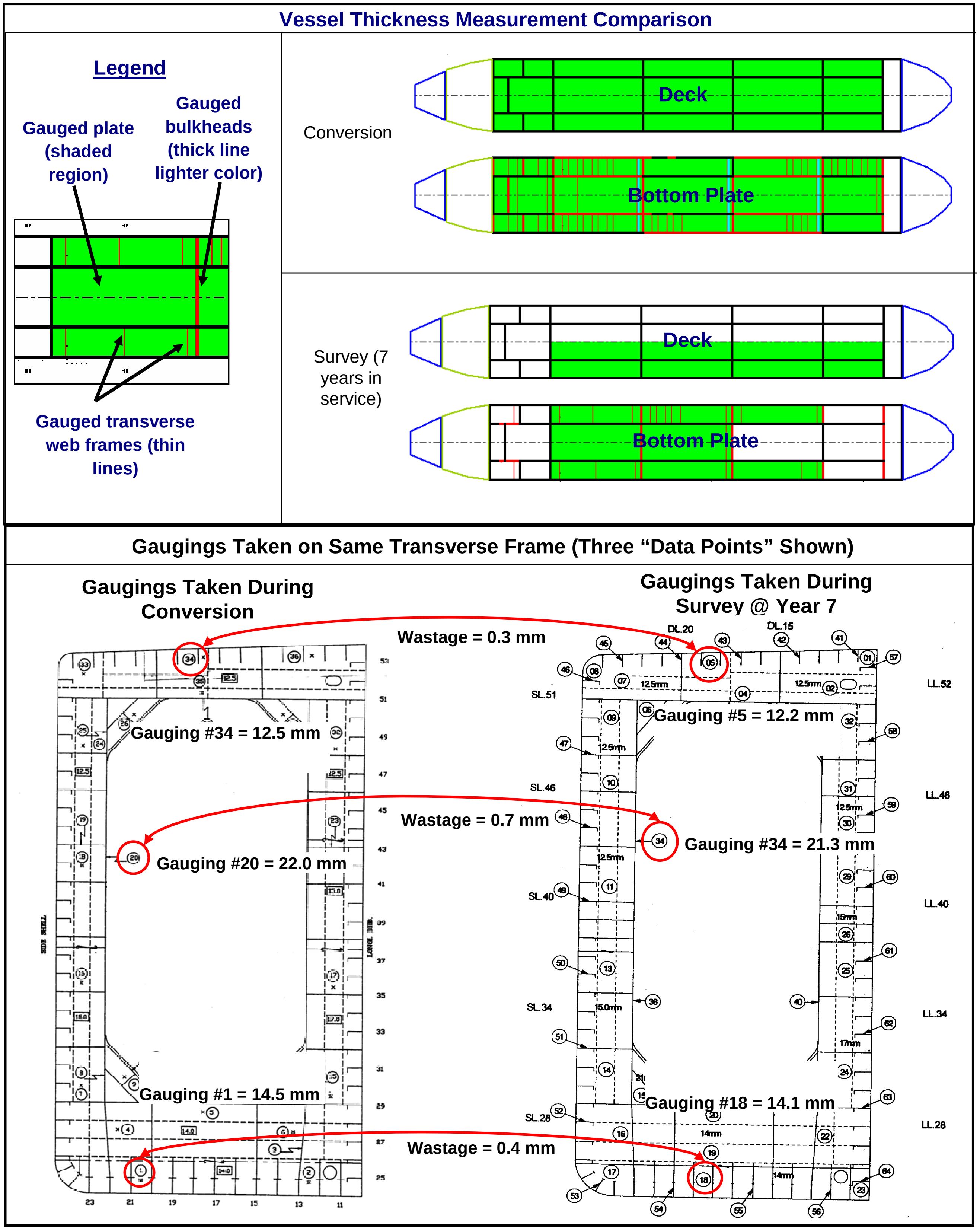
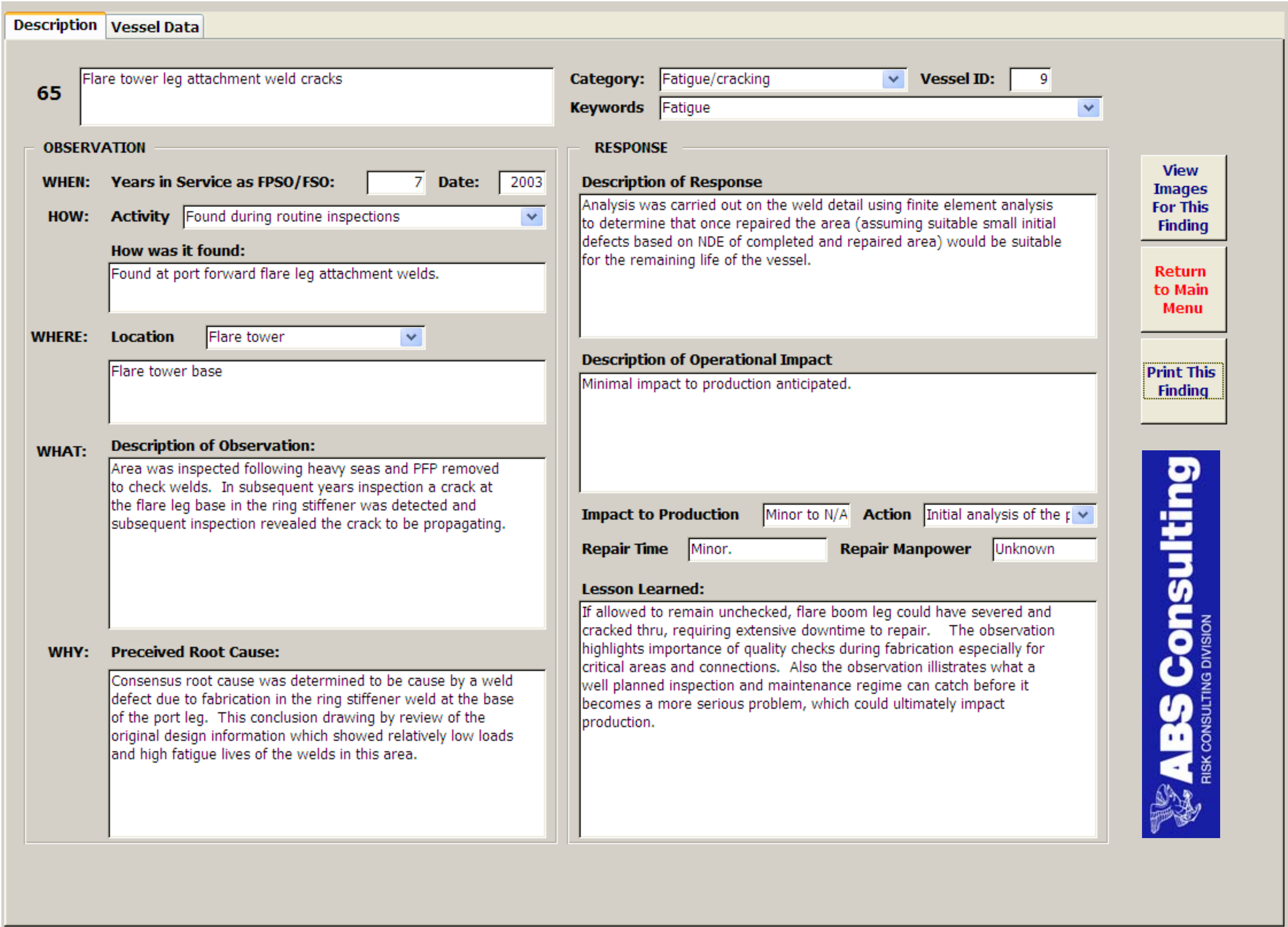


Figure 2: Typical Lessons Learned Data Sheet



Description | Vessel Data

65 — Flare tower leg attachment weld cracks

Category: Fatigue/cracking — Vessel ID: 9

Keywords: Fatigue

OBSERVATION

WHEN: Years in Service as FPSO/FSO: 7 — Date: 2003

HOW: Activity: Found during routine inspections

How was it found:
Found at port forward flare leg attachment welds.

WHERE: Location: Flare tower

Flare tower base

WHAT: Description of Observation:
Area was inspected following heavy seas and PFP removed to check welds. In subsequent years inspection a crack at the flare leg base in the ring stiffener was detected and subsequent inspection revealed the crack to be propagating.

WHY: Preceived Root Cause:
Consensus root cause was determined to be cause by a weld defect due to fabrication in the ring stiffener weld at the base of the port leg. This conclusion drawing by review of the original design information which showed relatively low loads and high fatigue lives of the welds in this area.

RESPONSE

Description of Response:
Analysis was carried out on the weld detail using finite element analysis to determine that once repaired the area (assuming suitable small initial defects based on NDE of completed and repaired area) would be suitable for the remaining life of the vessel.

Description of Operational Impact:
Minimal impact to production anticipated.

Impact to Production: Minor to N/A — Action: Initial analysis of the p

Repair Time: Minor. — Repair Manpower: Unknown

Lesson Learned:
If allowed to remain unchecked, flare boom leg could have severed and cracked thru, requiring extensive downtime to repair. The observation highlights importance of quality checks during fabrication especially for critical areas and connections. Also the observation illistrates what a well planned inspection and maintenance regime can catch before it becomes a more serious problem, which could ultimately impact production.

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Table 1: Example Corrosion Related Issues

ID	Description	Years in Service as FPSO/ FSO	Corrosion Type	Location	Perceived Contributing Factors
1	Capillary leak in side shell	18	Localized pit	Engine room in the lower region of the side shell	Possible substantial period of time elapsed with corrosive bilge water was trapped between the side shell longitudinal and side shell plate resulting in localized internal corrosion. At this location a pit developed internal that happened to coincide with a pit on the outer hull resulting in the capillary leak.
2	Coating breakdown and subsequent excessive localized corrosion	15	Localized corrosion	Oil tight bulkhead between slop tank and pump room	Coating within machinery space was allowed to deteriorate resulting in a region of transverse bulkhead plating that exceeded the wastage allowables. There was some contribution of corrosion loss on the slop tank side but majority was on the pump room side.
3	Coating breakdown and excessive localized corrosion and leak	6	Localized corrosion / pitting or possible defect	Void space side shell below the waterline	Region likely had standing water that was allowed to remain over a long period of time. Either the coating failure or existing coating defects resulted in extensive corrosion of the shell plating and small leak.
4	Coating breakdown and excessive localized corrosion throughout tank bottom	5	Extensive coating loss and pitting	Cargo reception tank bottom plating and bottom structure	The main reception tank corrosion protection system (i.e., hard coated bottom structure and anode back-ups) was of similar design as the cargo tanks. However, reception tank was exposed to significantly higher crude temperatures as well as more produced water than a normal cargo tank. Furthermore, the crude from some of the later new field production that came on line had higher hydrogen sulfide content.
5	Corrosion below minimal plate thickness allowables	7	General corrosion	Cargo storage tank bottom plating	The two cargo tanks in which this occurred were normally not used during the storage/offloading cycle and thus may have had water/oil standing undisturbed on the bottom for a long period time. Additionally, during the vessels tanker service there was evidence that bottom plating renewals were required in the past in these regions, potentially indicating that these wasted areas may have been pre-existing (i.e., at or near the minimal thickness allowables) and missed during the conversion.

Figure 3: Typical Fatigue Data – General Information

VESSEL FATIGUE PERFORMANCE SUMMARY

GENERAL VESSEL DATA		HISTORY/DESIGN LIFE	
Vessel ID:	7	Tanker Life:	N/A
Region/Location:	North Sea	Tanker Routes:	N/A
Type:	FPSO	FSO/FPSO Field Life:	20 years design life
Construction:	Single Hull, Double Sided , Newbuild	FSO/FPSO Life To Date:	8 years

ENVIRONMENTAL CONDITIONS/LOADING PATTERNS			
Wind	Mainly SW to NE at speeds to @ force 10	Parcel Offload Frequency:	Approx 20 days (down from 6-7 days at startup)
Currents	Generally NNE to SSW @ 1 knot	Offload Method:	Crude oil is oaded into Tank 4C (dedicated as the wet oil or reception tank), at 14 m level oil then cascades into 3C and 5C via balance lines at approximately 1m sounding. Cascade effect essentially provides even loading on tanks simultaneously. In addition to the 7 COT's there are two slop tanks for the reception of produced water and crude oil slops generated during tank cleaning ops. COT7 can also be used as reception if needed.
Waves	Sig wave max +/- 14.4 m. Max wave height +/- 26.5 m		
Roll	5-10 degrees, occasionally up to 15		
Comments	Vessel is fairly stable with high GM. Worst rolling occurs when residual swell lies across the run of tide (NE/SW). Winds predominately westerly, so rolling to be expected after strong westerly winds		

FATIGUE PERFORMANCE SUMMARY:	
General Comments:	Vessel has not experienced and fatigue or crack related problems to date. Weld details and key structural details are also provided for reference, where available.

OBSERVED CRACKING, IF ANY:									
LOCATIONS:	SEEN IN TANKER SERVICE	REPAIRED/CORRECTED **AT OR BEFORE CONVERSION?**	SUCCESSFUL?	RECURRED?	REPAIRED/CORRECTED **ON SITE?**	SUCCESSFUL?	RECURRED?	NOTHING DONE	COMMENTS
NONE									