6th International Conference
ðComputational Mechanics and Virtual Engineering ð
COMEC 2015
15-16 October 2015, Braşov, Romania

STRUCTURAL FATIGUE ASSESSMENT OF F(P)SO UNITS CONVERTED FROM AN OIL TANKERS

SorinBrazdis[1], MirceaModiga[2], Lucian V. Anghel[1],AlexandruCobzaru [1]
[1]ICEPRONAV Engineering, Galatzi, Roumania, email addresses: sorin.brazdis@icepronav.ro, lucian.anghel@icepronav.ro;alexandru.cobzaru@icepronav.ro
[2]Romanian Technical Academy, e-mail address: mircea.modiga@ugal.ro

Abstract:*The paper presents essential practical approaches concerning structural fatigue of floating (production) storage and offloading (F(P)SO) units converted from oil tankers. For this units it is very important to use an accurate service history to the correct evaluation of the accumulated fatigue damage, because they are much smaller than the values based on unlimited navigation conditions. All fatigue assessments are based on the Palmgren-Miner assumption and experimentally derived S-N curves. Simplified Method based on the widely accepted assumption that the long-term distribution of fatigue stress ranges fits a two-parameter Weibull cumulative distribution is used. Are discussed fatigue assessments in Initial Scantlings Evaluations (ISE) stage and further are performed fatigue FE Analysis for exclusive hull ship areas critical details and also for F(P)SO facilities and equipment (interface areas).*
Keywords:*FSO, FPSO, structural fatigue, FEA*

1. INTRODUCTION

ABBREVIATIONS
F(P)SO - Floating (Production) Storage and Offloading
DNV-GL - Det Norske Veritas-Germanischer Lloyd
ABS - American Bureau of Shipping
FDF - Fatigue Design Factor
ESF - Environmental Severity Factors (acc. ABS)
FEA - Finite Element Analysis
ISE - Initial Scantlings Evaluations (acc. ABS)
FEM - Finite Element Method/Model
ICE – International Contract Engineering Ltd.
ISE - Initial Scantlings Evaluations (ABS)
LC - Loading Case/Condition
RMS - Root Mean Squared
SIF - Stress influence factors
TSA - Total Strength Assessment (ABS)
WSD - Working Stress Design
VLCC - Very Large Crude Carrier

Fatigue damage of F(P)SO units is induced by cyclic loads due to environmental pressure, hull girder bending, ship motions, functional low-cycle loads (loading-offloading) and equipment operational loads. The chosen tanker has normally been subjected for short periods to fatigue loads resulting from sea states more severe than expected at the F(P)SO location, but overall the actual long term history of stresses may prove less damaging than provided for in the original tanker design. The usually milder environment at the F(P)SO site can nevertheless induce more damaging cyclic loads than those during trading life due to extended permanent exposure.
It is very important to use an accurate service history in predicting of the accumulated fatigue damage calculations for the trading period because the accumulated fatigue damage value based on the service history is,

generally, much smaller than the value based on unlimited navigation conditions. For instance, the accumulated fatigue damage during the trading period, calculated for some converted F(P)SOs ([8],[9], [10], [11]) based on the service history were calculated in a range of 0.18 to 0.28. If the unlimited navigation conditions had been used, the accumulated fatigue damage for the same period would have been evaluated in a range 0.7 ... 0.9.
All fatigue assessments for F(P)SOs are based on the assumption of linear accumulation of fatigue damage due to various stress range cycles and the experimentally derived *S-N* curves that provide the number of cycles to failure of a structural detail for given dynamic stress ranges. For the

$$S^{m_i} N = a_i \text{ , } i = 1, 2 \text{ ,} \tag{1}$$

formulation of the dual slope *S-N* curves that change slope at stress range S_0/N_0 the damage due to n_j dynamic cycles of stress range S_j is:

$$D_j = \frac{n_j}{N\left(S_j\right)} = \frac{n_j a_i}{S_j^{m_i}} \text{ ,} i = 1 \text{ for } n_j \leq N_0 \text{ and } i = 2 \text{ for } n_j > N_0 \text{ .} \tag{2}$$

The accumulation rule of Palmgren-Miner leads to the total fatigue damage experienced by a structural detail over *J* classes of dynamic stresses (S_j, n_j):

$$D = \sum\nolimits_1^J D_j \tag{3}$$

The same linear accumulation principle allows the breakdown of the total damage into unit life stages and, within each, into service periods in different loading and environmental conditions. For a FSPO typically:

$$D_{total} = D_{tanker} + D_{transit} + D_{site} \tag{4}$$

where the indices stand for the total damage, the damage during tanker life, the damage during the transit of the unit to the working site and the damage due to operations on site. The above damages are usually further broken down into:

$$D_{tanker} = D_{ballast} + D_{full} \text{ ;} \tag{5}$$

$$D_{site} = \sum_{i=1}^{n_{LC}} \sum_{j=1}^{n_P} \sum_{k=1}^{n_H} D_{i,j,k} \text{ ,} \tag{6}$$

where the site summations are for *LC*(loading conditions), load patterns considered in each loading conditions (n_P) and combinations of headings/loads (n_H).
In an exact approach the dynamic stress history in each stage is to be rainflow counted into stress range intervals, which is rarely feasible. For F(P)SOs and with respect to fatigue dominating wave effects even the second best approximation provided by the spectral fatigue method proves highly demanding in complexity and numerical resources, making it an option not often taken by the owners. The experience gathered in fatigue assessments for F(P)SOs relies on the so-called Simplified Method based on the widely accepted assumption that the long-term distribution of fatigue stress ranges fits a two-parameter Weibull cumulative distribution. This allow the following closed-form equation for the damage in a given unit condition formulation [5] is presented, equivalent to the one in [3]:

$$D = n\left[\frac{q^{m_1}}{a_1}\Gamma\left(1+\frac{m_1}{h},\left(\frac{S_0}{q}\right)^h\right) + +\frac{q^{m_2}}{a_2}\gamma\left(1+\frac{m_2}{h},\left(\frac{S_0}{q}\right)^h\right)\right] \tag{7}$$

where *n* is the total number of wave cycles, γand Γare the incomplete and complementary incomplete Gamma functions and *q* and *h* are the scale and shape parameters of the Weibull distribution.
Formulations in number of cycles are generally presented in this paper for simplicity. However these are rarely counted but rather estimated based on an average wave period/frequency *T/ν* and the time spent by the unit in the given condition. The average period is to be taken as the average of the zero up-crossing periods of all sea states in the long-term period, weighted by the probabilities of occurrence of the sea states; empirical formulae are also available in rules, e.g. [3]. The time spent by the unit in a given condition is usually expressed by its fraction to the total life in a given unit stage, tanker or F(P)SO.
The Weibull parameters are in principle to be tuned for a best fit to the Weibull distribution through an iterative procedure. In practice good approximations for the shape parameter for F(P)SO are recommended in rules through empirical formulae, e.g. in[3]for both F(P)SO and tanker and F(P)SO life, and the necessary scale parameter results for a reference number of cycles N_R and the corresponding stress range S_R of probability of exceedance $1/N_R$ as:

$$q = \frac{S_R}{\left(\ln N_R\right)^{1/h}} \tag{8}$$

For F(P)SOs the reference stress level for fatigue is taken at 10^{-4} probability of exceedance (daily return period).

The current *S-N* curves provided by classification societies are built to a 97.7% probability of survival. Therefore typical designs will take further allowance through a *FDF*;the fatigue criteria in damage formulation is thus:

$$D \leq 1/FDF \ , \ FDF \geq 1.0 \tag{9}$$

Fatigue assessments are typically conducted considering the appropriate corrosion wastage for the structural details during both past tanker and future FPSO service. This is generally assumed to be linear in time and the midlife net thickness was considered for fatigue assessments in several works. For the past tanker life the calculation thickness was taken as the average of the gauged and tanker as-built thicknesses; for the F(P)SO life it was taken as the gauged/renewed thickness less half the nominal corrosion margin specified by the Class. The approach has been applied in association with *FDF*=2. However, with the current provisions of [3**]**, a net thickness approach is considered (gauged thickness for trading tanker life, gauged/new thickness less full nominal corrosion for F(P)SO service). A reduction factor of 0.95 to the reference dynamic stress range is allowed instead of considering the effects of thicker structural members in early service stages. Overall the current net thickness approach is considered to provide sufficient margin to safely consider *FDF* =1.0 for F(P)SOs.

The list of the structural details to be checked for fatigue is based on the requirements of the classification societies and the designer's past experience. This list includes but is not limited to:

- end connections of longitudinal stiffeners to transverse web frames and to transverse bulkheads;
- ends or bracket ends of primary supporting members;
- flanges of transverse web frames in way of tripping brackets;
- topside and crane pedestal connections with the main deck;
- mooring integration structure with hull;
- flare tower, riser balcony or turret connection with hull.

2. FATIGUE ASSESSMENTS IN ISE STAGE

The dynamic stress ranges that occur in the hull longitudinal stiffeners are mainly due to longitudinal hull girder bending. The details of the longitudinal stiffeners' end brackets have a simple geometry and well-defined load direction which means the nominal stress approach is applicable. Therefore, a quick evaluation of the remaining fatigue life of these details may be performed during the ISE design phase. The specific software released by the classification societies for the scantling evaluation also include modules for the remaining fatigue life calculation of the longitudinal stiffeners' end brackets considering fatigue damage ratios both for the prior service to conversion and for post conversion phases. The assessment rely on the calculated α-type ESFs for the trading tanker routes history and the operational site, respectively.

As a possible solution for details found not to meet the fatigue criteria new and/or modified end brackets are proposed in order to increase the fatigue life with minimum steel renewals. Figure 1 shows such improvements after the results of the ISE fatigue assessment ([9**]**) of longitudinal stiffeners'. The weakest details presented are the end connections of the longitudinal stiffeners placed on the splash area of the side shell.

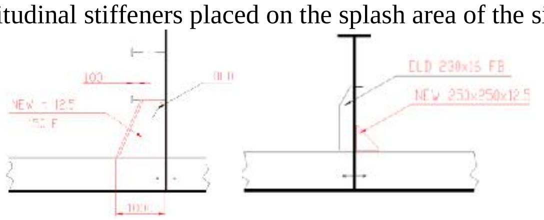

Figure1: Typical solutions in ISE stage for end connections not meeting fatigue criteria – replacement (top) and additional (bottom) new brackets

It is to be noted that the approach is mainly applicable to stiffeners in exclusive ship areas. For hull stiffeners in way of static F(P)SO facilities and equipment (i.e. that exert only inertial loads on the hull structure, e.g. topside stools, pipe racks) which are considered in interface areas the approach can also be employed as long as the higher FDFs are considered. However more accurate damage assessment of the longitudinal stiffeners' end brackets based on FEA are usually preferred for the interface areas; for locations placed in way of F(P)SO equipment introducing dynamic operational loads (mooring and riser systems, cranes etc.) the FEA based approach is mandatory.

3. FATIGUE ASSESSMENTS FOR SHIP AREAS CRITICAL DETAILS

Further fatigue assessments are performed for the critical hull locations based on FEAs with local fatigue FEM.For the local FEA of ship critical areas the software automatically:

- builds loads (hull girder bending and shear, external and internal pressures and body accelerations) for the parent 3-tank length FEM and solves it for displacements;
- applies displacement boundary conditions on the local FEMs and rebuilds the loads on it;
- allows performing Local FEAs.

FE Analyses are performed for both trading tanker life and F(P)SO service. Additionally the software automatically calculates the fatigue damage using the long term simplified method in the following approaches.

For F(P)SO service, analyses are performed according to ABS (2015) for four loading conditions spread evenly between minimum ballast and full load. A single load pattern is considered for each loading condition and eight load combinations specially tailored for each loading condition are applied grouped in four sagging/hogging pairs for the heading angles of 0 (head sea), 30, 60 and 90°. Four stress ranges are extracted as the difference between stresses resulting from the two LCs in each pair. Damages calculated for heading conditions are accumulated based on their probabilities of occurrence, as provided from a heading analysis if available or following recommendations of ABS (2015). Damages calculated for the loading conditions are accumulated assuming a 15% probability of occurrence for the ballast/full load conditions and 35% for the intermediate ones.

For the trading tanker life also according to ABS analyses ([3**])** are performed for the same base eight combinations of loading conditions and patterns and the eight LCs used for TSA. Four stress ranges are extracted from pairs of the LCs and damage is calculated for the most unfavorable one (actually only two pairs may be assessed for certain locations on ships, e.g. deck, bottom, mid-depth and transverse bulkhead).

However, in practice, in order to obtain a more accurate estimate of the damage during past voyages the full long term history is split into several shorter periods by grouping together routes of similar β factors. Damages are calculated for the shorter long-term periods of trading with conservative β factors and are accumulated by direct summation into the total tanker damage. Overall, assessment of the damage during past tanker life requires a comparable workload to the assessment of expected damage during F(P)SO service.

The damage from the transit of the unit to the operations site is in principle calculated similarly to the one for on-site operations. There is a single ballast condition to be accounted for and part of the LCs could be discarded for the absence of internal pressures.

In the ABS approach, implemented in the ABS Eagle FPSO software, the loads applied on the FE are always taken at 10^{-8} probability of exceedance (20 years return period) with corresponding β factors for past trading routes and F(P)SO service on site. The 10^{-4} long-term probability of exceedance reference stress ranges are then derived by applying a 0.5 factor to the stress ranges induced by the above.

The mesh size for the fatigue FEM is refined down to the local plate thickness t in the areas of structural details of interest. Special stress recovery techniques are used for free edges - the stress ranges are fetched from rod elements of insignificant stiffness purposely added to the model (cross section area of 1 mm^2). For fillet welds at bracket toes, hotspot stresses at the weld toe location are calculated by the well-established and widely used interpolation process on the principal stresses closest to the perpendicular to the weld line on four elements ([3], [5]) - cubic interpolation is used to derive the stress ranges at $0.5t$ and $1.5t$ away from the weld toe; linear extrapolation is used with these to extract the stress range at the weld toe). In all cases corrections for members of thickness larger than the reference t_R provided with the S-N curves are applied in the appropriate format; see e.g.[4],[5] -an amplification factor of $(t/t_R)^{0.25}$ for the stress ranges is introduced typically. All considerations in this paragraph are applied in direct Femap/Nastran FEA and damage calculation outside Class Software as well.

Figure 2 present two hull details analyzed in ([9]) with the ABS Eagle FPSO software. The top part present the free edge of a hole in the centre line bottom girder connection to a transverse bulkhead. The bottom part presents the toe of a bracket connecting a side shell stiffener to a transverse bulkhead.

The charts on the right present ratios of stress ranges on site to permissible fatigue stresses used in screening the locations for damage calculations (permissible fatigue stresses can be derived using a unit damage; calculated values for the standard design life of 20 years are provided in Class rules).

The actual damage calculations ran with the *S-N* curves ([4]). For the free edge these were based on the *C*-curve and employed nominal stresses on the fictitious rods (not visible in the picture).

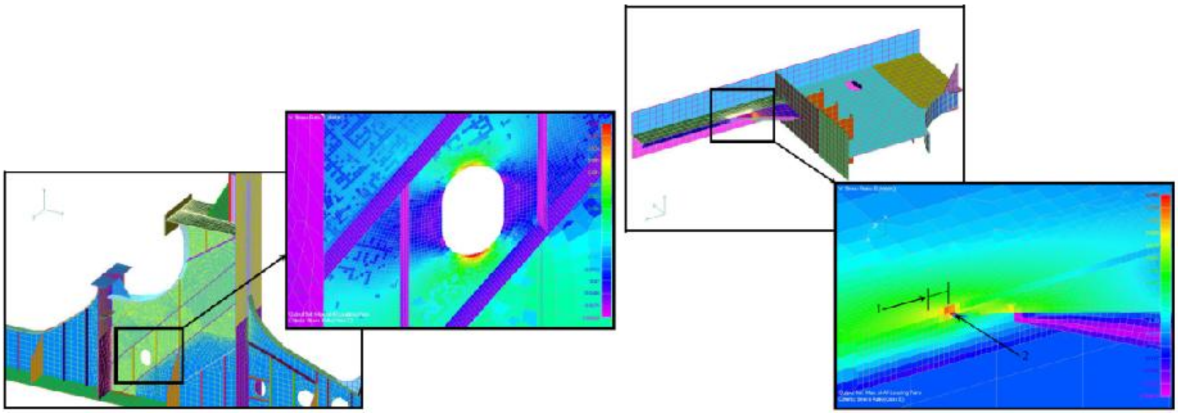

Figure 2: Hull (ship area) fatigue detail analyzed with ABS Eagle FPSO Software for a single hull FPSO

For the bracket toe the transverse weld toe on the stiffener flange was checked on the *E-curve* with the hotspot stresses interpolated from the nominal stresses on the four plate elements indicated by arrow 1; the longitudinal weld toe on the bracket was also checked on the *E* curve with the nominal stress on the element indicated by arrow 2. The bracket end was previously updated out of strength requirements and only the transit and FPSO damages are calculated; due to the update the estimated total damages for both weld toes were found below 0.5.

4. FATIGUE ASSESSMENTS FOR F(P)SO FACILITIES AND EQUIPMENT

The main effort in damage assessments for F(P)SO equipment and facilities is for their foundations and supporting structures. All of these, including the hull structures below the main deck or inside the hull shell, are classified in the latest versions of [3] as hull interface areas for which the adoption of unit *FDF* is no longer accepted. For these FDF is to be taken between 2 for non-critical, inspectable and repairable structural details and 10 for critical and non-inspectable/repairable ones.
The structures outside the hull shell will typically be new to the unit and hence the damage from tanker life is zero. The structures within the hull shell are generally inherited from the converted tanker and damage accumulated during tanker life can be fully assessed by means of the Class software.
For the assessment of expected damage during F(P)SO service of supporting structures of newly installed equipment and facilities advantage is also usually taken of the services provided by Class Software, to various levels of extent. The software provides direct and full support for the topside stools, allowing either the modeling of the topside modules including their weight or direct input of vendor supplied reaction forces. The approach can be employed also to all equipment in the midship area where 3-tank length models are supported by Class Software to find the damage from wave-induced cyclic loads on site. For static equipment, e.g. topside stools and pipe-racks, this is also the total damage on-site.
The most challenging may prove the fatigue assessment for equipment and facilities that introduce dynamic operational loads aside from the inherent inertial loads due to the vessel's motions in waves. Usually the dynamic cyclic loads from such equipment exert at frequencies different from the waves frequency, or at least with inconsistent phases. The effects of the simultaneous dynamic processes of waves and operational loads are combined into a total damage based on the separately calculated damages as:

$$D = D_w\left(1-\frac{T_w}{T_o}\right)+\frac{1}{T_o}\left[\left(D_wT_w\right)^{1/m}+\left(D_oT_o\right)^{1/m}\right]^m \quad . \tag{10}$$

The combination law was derived based on a single slope *S-N* curve ([5]). Here the indices "*w*" and "*o*" refer to waves and operational processes respectively, *T* are the average zero up-crossing periods of each process and *m* is the slope of *S-N* curve. The law can be applied to dual-slope *S-N* curves and is proved to be conservative when using the large cycle range branch exponent, $m=m_2$. All damages are relative to the site operations of the unit.
The operational damage is usually assessed based on the same fatigue refined models used for waves induced damage exported from the Class software to an all-purpose linear FE solver package. The choice for previous works was the Femap/NX Nastran package and the export usually transfer also the boundary conditions.
A simpler case of equipment with distinct operational loads of relevance to fatigue are the F(P)SO on-board cranes. Usually a comprehensive analysis of the distribution of operational loads over time will not be available and the designer will have to rely on the following approach, albeit overly conservative. Stresses are to be obtained in the structural detail of interest for LCs built for a significant number of boom angles and the maximum rated crane load. A maximum stress range is to be established as the maximum difference between

any pair of these (typically this will result for two boom positions at a relative angle of 180º). A number of cycles n_o is taken according to the crane certification class. The operational damage is directly calculated on the applying *S-N* curve with the maximum stress range and n_o above. For combining with the damage due to waves the operational loads period can be taken as the F(P)SO service life divided by n_o.

The most demanding fatigue assessments for F(P)SO facilities are usually the ones for the supporting structures of permanent mooring systems (either spread mooring or single point mooring, with either internal or external turrets), and dynamic riser systems. Operational loads from these are usually provided by the mooring/riser system vendor on a short-term basis following the systems' hydrodynamic analyses. For fatigue assessment purposes the vendor must provide also the RMS (root mean squared, usually computed as the square root of the zero-order spectral moment of the power spectrum density in a short-term sea state) and the zero up-crossing period of the loads. The data is to be provided for a number of sea states representative for the operational site long-term environment and, in an optimum scenario, for each sea state for a relevant number of combinations of headings and wave relative directions to current.

By taking a simplification assumption based on the FEA linearity the RMS of stresses in the fatigue structural details σ are extracted following a FEA with the fatigue fine FEM loaded with the RMS values of the operational loads. Considering that the short term stress variation follows a Rayleigh probability distribution, a closed-form equation for the damage in a given sea state *k* and heading *h* due to operational loads is obtained for a dual-slope *S-N* curve as:

$$D_o^{k,h} = n^{k,h}\left[\frac{\left(2\sqrt{2}\sigma^{k,h}\right)^{m_1}}{a_1}\Gamma\left(1+\frac{m_1}{2},\left(\frac{S_0}{2\sqrt{2}\sigma^{k,h}}\right)^2\right)+\frac{\left(2\sqrt{2}\sigma^{k,h}\right)^{m_2}}{a_2}\gamma\left(1+\frac{m_2}{2},\left(\frac{S_0}{2\sqrt{2}\sigma^{k,h}}\right)^2\right)\right] \tag{11}$$

$$D_o = \sum_k \sum_h D_o^{k,h} \tag{12}$$

The equation is usually employed in spectral based fatigue analyses ([4]). $n^{k,h}$ is the number of operational load cycles expected in the sea state and heading condition estimated based on the zero up-crossing period provided by the vendor, $T_z^{k,h}$. The total operational damage on site D_o is accumulated linearly and, when it is to be combined with the damage from waves, T_o is to be taken as the duration weighted average of $T_z^{k,h}$.

The equation above was provided for clarity considering the loads from mooring and riser systems are narrow band dynamic processes. This is generally not true, cyclic loads being exerted at both wave (high) frequency and at a lower frequency due to second-order wave effects. The vendor supplies data for both regimes (σ_H, T_{zH}) and (σ_L, T_{zL}). The combined spectrum method can be employed ([3], [6]), in which the damage calculation is to be performed with the combined parameters:

$$\sigma = \sqrt{\sigma_L^2 + \sigma_H^2} \tag{13}$$

$$T_z = \sigma\left(\left(\sigma_L/T_L\right)^2 + \left(\sigma_H/T_H\right)^2\right)^{-1/2} \tag{14}$$

The combination is actually performed in terms of operational loads instead of stresses and the resulting RMS applied as load in FEA. The approach is known to be highly conservative and one can adopt the dual narrow-banded approach which introduces an additional sub-unit factor for the RMS.The total number of sea states can be 50 or larger and within each eight or more heading and other environmental variations can be considered. Also, especially for the *riser systems*, the loads apply on a significant number of slots with strong inter-influence for the local structural details of each other and in certain cases various scenarios of combinations of used/unused slots may be required to be analyzed. In order to reduce the number of performed FEA usually a SIF approach is employed in which FEAs are performed for unit values of each load component on each slot (for mooring there will generally be a single axial load, the mooring line tension; for risers there are usually also bending and shear loads at their connection points). The stress RMS for a given finite element in the sea state *k* and heading condition *h* is then recovered as:

$$\sigma^{k,h} = \sum_S \sum_C SIF_{S,C} L_{S,C}^{k,h} \tag{15}$$

where $SIF_{S,C}$ is the elemental stress influence factor due to component *C* on slot *S* and $L_{S,C}{}^{k,h}$ is the RMS of the load component *C* acting on slot *S* in the sea state *k* and heading condition *h.*

Fig.Error! Reference source not found. presents the FEM used for the fatigue assessment of a mooring skid bracket toe ([9]) grouping the connection points of mooring lines 4 to 6. In this case the loads RMS and periods were only provided for the most unfavorable heading in each sea state; instead six combinations of lines angles were required to be scanned to find the most damaging configuration. By dropping the indexes *h* and *C* in the equation above SIF where calculated for both slots *S* =4, 6 and line angles *A* =1, 6 and the calculation RMS for sea state *k* was taken as

$$\sigma^k = \max_A \sum_{S=4}^{6} SIF_{A,S} L_S^k \tag{16}$$

In order to avoid a numerical loss of accuracy the SIF where computed by FEA for unit loads of 1000 *kN*. For the hotspot detail assessed on the *S-NE*curve the actual maximum in the equation was taken after finding the maxima between interpolated values from elements in groups marked *a* and *b* in the figure for each A. Subsequent to FEA derivation of SIF all calculations were performed based on spreadsheet for 50 sea states.

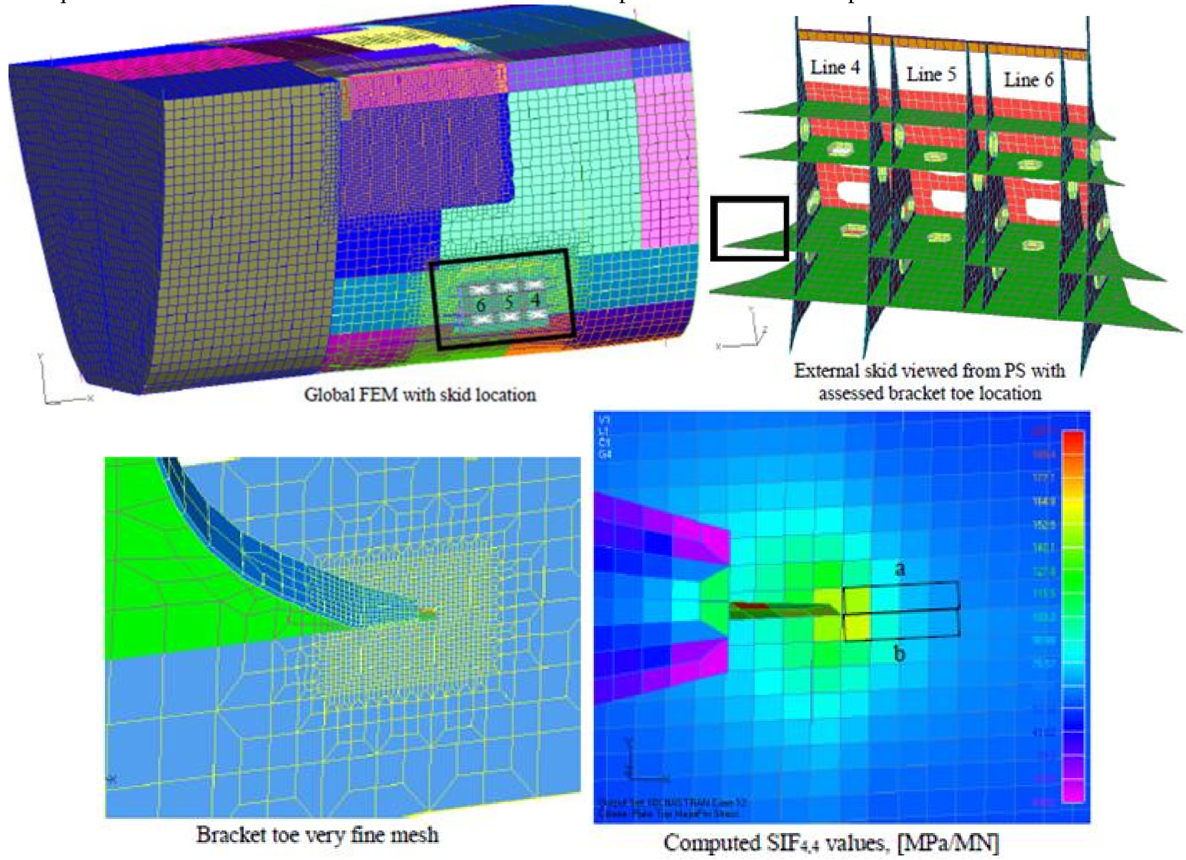

Figure3:Fatigue assessment for an interface area bracket toe of an aft spread mooring skid ([9])

Certain F(P)SO equipment and facilities are located at the vessel's ends, e.g. off-loading stations, flare towers and helidecks; typically no operational loads of relevance to fatigue are associated with the equipment. In this cases no support can be found in the Class software and all fatigue assessments are based on FEAs performed with all-purpose linear FE solvers. The models are built to the Class recommendations similar to chapter 5.2 and for the waves induced damage pairs of LCs of essentially opposite directions of loads are applied also per Class provisions. The loads are typically taken at 10^{-8} probability of exceedance level and include vertical bending moment, body accelerations and internal and external pressures (including slamming and green water pressures as applicable). The equipment inertial loads are applied through either concentrated masses or vendor supplied reaction forces of consistent directions to each LC. Stresses in fatigue details are established following FEAs and damage is calculated through in-house developed spreadsheets that reproduce the approach presented in p.2.
As discussed in chapter 4 above most of the structural analysis for the offshore parts of the F(P)SO equipment and facilities are performed by vendors. Usually only the helideck remains in the marine designer scope of work. When requested, fatigue checks for the tubular joints are performed for wave-induced inertial loads using in-house spreadsheets according to the requirements of**[**7**]**.

5. CONCLUSIONS

In the case of the conversion from an existing tanker the work required in fatigue assessment is further enlarged, typically doubled, due to the iterative process employed in establishing the minimum reassessed scantlings that meet the hull girder strength and the need to assess the fatigue damage for both the trading tanker life and the F(P)SO service.
A trading tanker is often originally designed for harsher conditions than what it will experience as an F(P)SO hull during its remaining life; by carefully evaluating these facts as well as the trading history of the tanker the

designer can in many cases reduce or eliminate the need for steel replacement even taking into account corrosion wastage and without increasing the risk for structural failure.
There are well-established methodologies to achieve the required analyses. The major classification societies have available software packages that can be used to great advantage. Particularly for integration of a wide variety of equipment and facilities needed for the service as an F(P)SO the standard packages will need to be supplemented by ad hoc analyses using standard tools.
Throughout the paper, examples of structural issues and successfully applied improvements to them are presented, and certain techniques beyond the Class requirements that allow tackling complex and extensive tasks are described.

6. ACKNOWLEDGEMENT

The authors gratefully acknowledge the grant support received to carry out the work presented in this paper as an integral part of INTERNATIONAL CONTRACT ENGINEERING LTD (ICE) funded projects. The content of the publication is the sole responsibility of the authors, and ICE is not liable for any use that may be made of the information.

REFERENCES

[1] Brazdis S., Modiga M., Dimitriu C., Cobzaru A., *Hull Condition Analysis - first stage of an oil tanker conversion into F(P)SO*, Proc. of10th edition The days of the Academy of Technical Sciences of Romania, Galaţi, October 9-10, 2015
[2] Brazdis S., Modiga M., Anghel L. V., Coreschi C., *The structural evaluation of a F(P)SO unit converted from a oil tanker*, Proc. of 10th edition The days of the Academy of Technical Sciences of Romania, Galaţi, October 9-10, 2015
[3] ABS (2015), *Rules for Building and Classing Floating Production Installations*
[4] ABS (2014), *Guide for the Fatigue Assessment of Offshore Structures*
[5] DNV-GL (2014), DNVGL-RP-0005, *Fatigue Design of Offshore Steel Structures*
[6] DNV (2013), OS-E301 *Position Mooring*
[7] API RP 2AWSD (2007), *Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms - Working Stress Design*
[8] ICE (2005), *VLCC to Cidade de Vitoria FPSO Conversion, Detail Engineering*
[9] ICE (2007), *VLCC to Gimboa FPSO Conversion, Detail Engineering*
[10] ICE(2010), *VLCC to FPSO Conversion Study for JUBILEE and TUPI sites*
[11] ICE (2012), *VLCC to FPSO Conversion Total Strength Assessment*.