SIMPLIFIED PROCEDURES FOR FATIGUE ASSESSEMENT OF THE WELDED JOINTS OF A SHIP STRUCTURES

Dan Birsan[1]

[1] *"Dunarea de Jos" University of Galati, dbirsan@ugal.ro.*

Abstract: *In this paper is presented the evaluation of fatigue strength of a structure subjected to alternating symmetrical stresses with a high frequency. The analysis is a simplified one and is based on the evaluation of the welded joint of a bracket toe of a support structure on a ship's equipment. The fatigue evaluation was performed based on the local finite element model with very small elements (mesh t x t), which gives the correct results in areas where the highest stress ranges have been recorded.*

Keywords: *fatigue analysis, finite element, stress*

1. Introduction

The scope of this document is to present the fatigue strength capability of an equipment supporting structure situated on the main deck of a FSO (Floating Storage and Offloading).

The fatigue analysis should be based on S-N data, determined by fatigue testing of the considered welded detail, and the linear damage hypothesis. When appropriate, the fatigue analysis may alternatively be based on fracture mechanics. If the fatigue life estimate based on S-N data is short for a component where a failure may lead to severe consequences, a more accurate investigation considering a larger portion of the structure, or a fracture mechanics analysis, should be performed.

A simplified fatigue analysis methodology was performed for the most stressed longitudinal bracket.

The following steps have been followed to perform the fatigue check:

- screening analysis: using the yielding stress results, the most fatigue-prone longitudinal brackets were identified;

- fatigue life calculation: checking of the fatigue limit state (FLS) of the identified details based on the refined FE analysis.

In welded structures fatigue cracking from weld toes into the base material is a frequent failure mode. The fatigue crack is initiated at small defects or undercuts at the weld toe where the stress is highest due to the weld notch geometry. A large amount of the content in this RP is made with the purpose of achieving a reliable design with respect to this failure mode.

The fatigue life may be calculated based on the S-N fatigue approach under the assumption of linear cumulative damage (Palmgren-Miner rule).

2. Model description

The following types of elements are used to model the equipment supporting structure:

- Plate elements for parts of the equipment supporting pipes, platform, brackets, decks, girders and the web of HP stiffeners;
- Bar elements for equipment supporting structure pipes, flanges of girders and of some brackets;
- Rod elements for bulb of HP ordinary stiffeners;
- Rigid elements for connections between the master nodes placed at the COG's of the equipment and its slave nodes.

An overview of the full 3D-FE model used for the linear static calculation is shown in Fig.1.

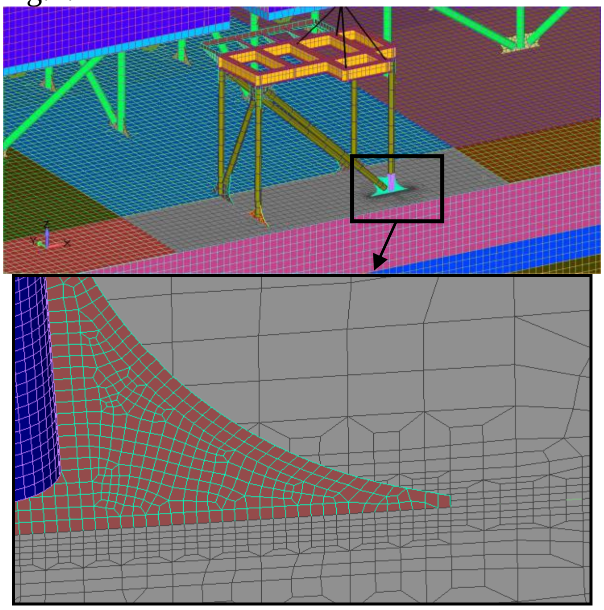

Figure 1: *3D-FE model*

2.1 Loads and load combinations

2.1.1 Hull Girder Loads

The hull girder loads have been taken into consideration and are imposed by enforced rotation, longitudinal direction translation and vertical direction translation for the nodes of the fore end and lower section of hull structure.

Table 1 shows the daily bending moments used for fatigue calculations.

Table 1: *Hull girder bending moments for fatigue calculations*

Wave BM	Daily bending moments [kNm]
LC-S	-1600000
LC-H	1500000

2.1.2 Weight and Inertia Loads

The inertia loads acting on the equipment and its supporting structure, on X, Y and Z direction, are taken into account by using the longitudinal (a_x), transversal (a_y), and vertical (a_z) accelerations. They have been modelled as body accelerations and applied to the entire model.

Table 2 shows the daily accelerations used for fatigue calculations.

Table 2: *Accelerations for daily return period*

	a_x[m/s²]	a_y[m/s²]	a_z[m/s²]
LC-S	0.6	1.5	-1.2
LC-H	0.7	1.9	1.4

The environmental fatigue damage on site, D_{Env}, was determined using the conservative simplified fatigue calculation presented in Ref. 0– Ch.4.

According to Ref. 0, the long term distribution of stress ranges at local details may be described by the Weibull distribution:

$$Q(\Delta\sigma) = \exp\left[-\left(\frac{\Delta\sigma}{q}\right)^h\right]$$

where:

- Q = probability of exceedance the stress range $\Delta\sigma_{env}$;
- $h = h_0 = 2.21 - 0.54\log_{10}(L) =$ 0.924 - Weibull shape parameter;
- $q = \frac{\Delta\sigma_O}{(\ln n_0)^{1/h}}$ Weibull scale parameter;
- $\Delta\sigma = \Delta\sigma_0\left[\frac{\ln n}{\ln n_0}\right]^{1/h}$ - stress range distribution ;
- $\Delta\sigma_0 = \Delta\sigma_{Env}$ – the largest stress range for;
- L = 240.89 m – rule scantling length.

The fatigue design is based on use of S-N curves which are obtained from fatigue test. The S-N curves are presented as straight lines in a log-log scale, and the S-N curve in air is often presented as bi-linear a change in slop beyond 10^7 cycles.

According to Ref. 0 when the Weibull (bi-linear) distribution and a two-slop S-N curves are used, the total environmental fatigue damage (D_{Env}) is given by the following formula:

$$D_{Eenv} = \nu_0 T_d\left[\frac{q^{m_1}}{\bar{a}_1}\Gamma\left(1+\frac{m_1}{q};\left(\frac{S_1}{q}\right)^h\right)+\frac{q^{m_2}}{\bar{a}_2}\gamma\left(1+\frac{m_2}{h};\left(\frac{S_1}{q}\right)^h\right)\right] \le \eta$$

3. Results

For the fatigue check of the **weld seam**, was selected the S-N curve "D" that is specific for the hot spot stress methodology, as presented in Ref. [1] – Sec. 4.3.5. The stress concentration or the notch factor is included in the "D" S-N curve in air presented in Table 2-1 from Ref. [1], Ch. 2.4.4.

- $\nu_0 = 1/T_z$ – average zero-crossing frequency;
- $T_z = 8.64$ [s] (conservative average zero-crossing period on site operational);
- $T_d = 12$ years – design life in seconds, the FSO design life is 12 years;
- $m_1 = 3$, $\log \bar{a}_1 = 12.164$ - intercept of log N axis for $N \leq 10^7$ cycles, from the "D" S-N curve in air presented in Ref. [1] – Ch. 2.4.4 – Table 2-1;
- $m_2 = 5$, $\log \bar{a}_2 = 15.606$ - intercept of log N axis for $N > 10^7$ cycles, from the "D" S-N curve in air presented in Ref. [1] – Ch. 2.4.4 – Table 2-1;
- $S_1 = 52.63$ [N/mm^2] – stress range for which the S-N curve change the slop, for "D" S-N curve;
- $\Gamma(;)$ – complementary incomplete gamma function;
- $\Upsilon(;)$ – incomplete gamma function.

According to Ref. [2], Sec.10, the stress at the read out points is established as described in the following. Alternatively the nodal stresses may be used provided that they are derived directly from the calculated element stresses within each element.

For 4-node shell elements with $t/2 \leq$ element size $\leq t$ the following steps must be applied:

- element surfaces stress at the centre points is used as illustrated in Fig.3a;
- the stress at the element centre points are extrapolated to the line A-A as shown in Fig.3b to determine the stress at read out points;
- if the mesh density differ from t x t, the stresses at the stress read out points are determined by interpolation as shown in Fig.3c.

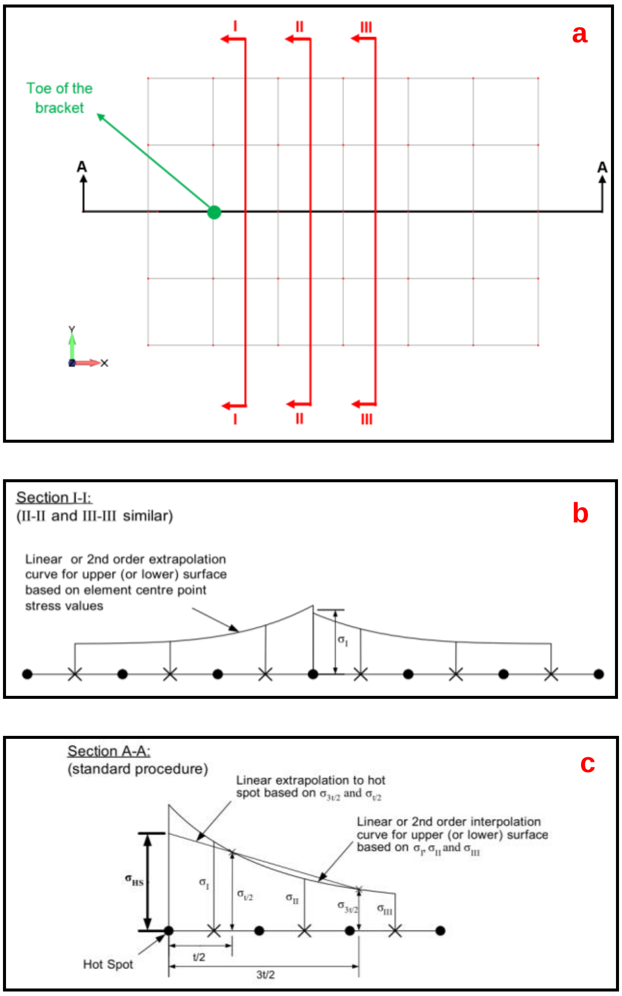

Figure 3: *Determination of stress read out points and hot spot stress for 4-node shell elements*

Two loading cases have been considered for fatigue check of the weld seam, LC-H1 and LC-S1.

The plate principal stress angle for LC-H1 case is shown in Fig. 5 and due to angle values the Major Prn. Stress has been considered in hot spot stress calculation.

For LC-S1 case the principal stress angle can be seen in Fig. 11 and for hot spot stress calculation, the Minor Prn. Stress has been considered.

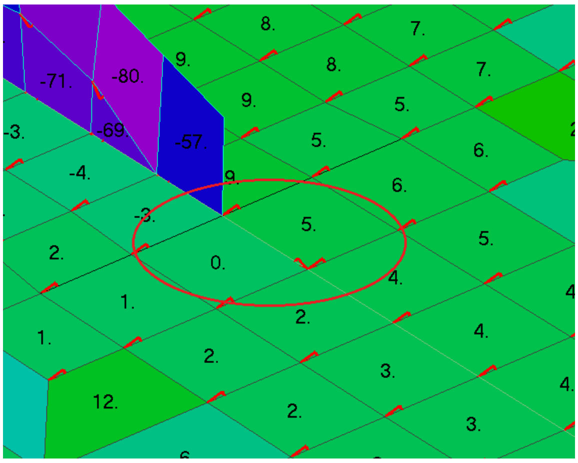

Figure 4: *Plate Top Prn. Stress angle, LC-H1*

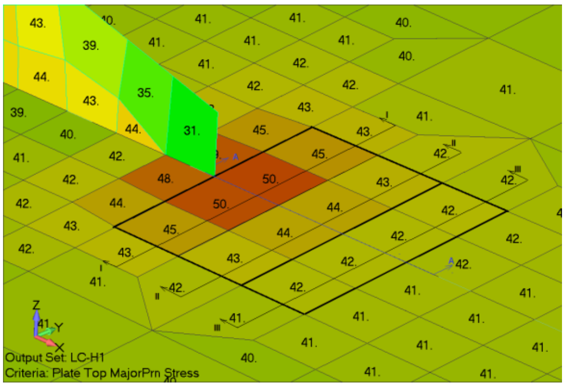

Figure 5: *Environmental stress for weld seam fatigue check, Major Prn. Stress, LC-H1*

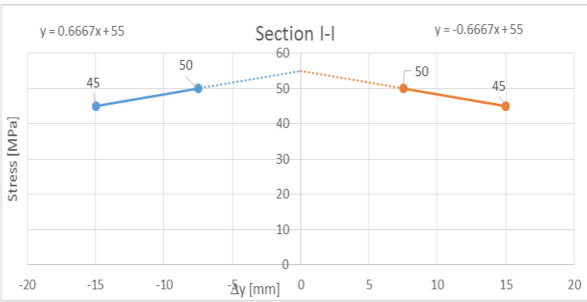

Figure 6: *Linear extrapolation curve for upper surface based on element centre point, Major Prn. Stress value, Section I-I (see Fig.5)*

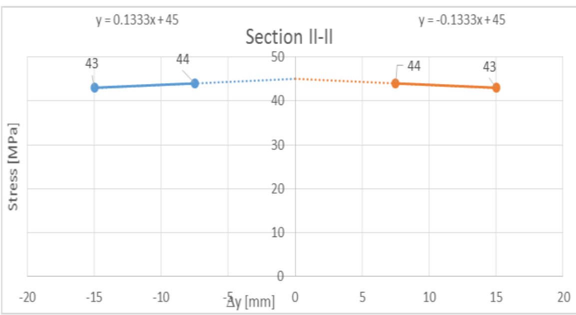

Figure 7: *Linear extrapolation curve for upper surface based on element centre point, Major Prn. Stress value, Section II-II (see Fig.5)*

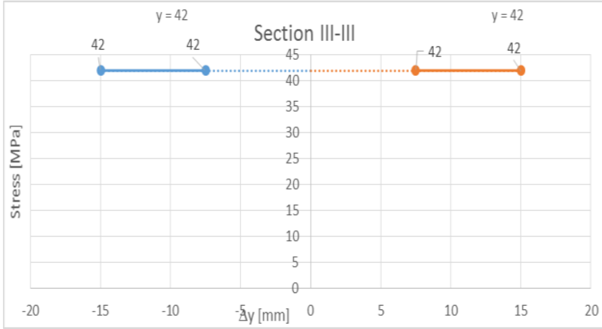

Figure 8: *Linear extrapolation curve for upper surface based on element centre point, Major Prn. Stress value, Section III-III (see Fig.5)*

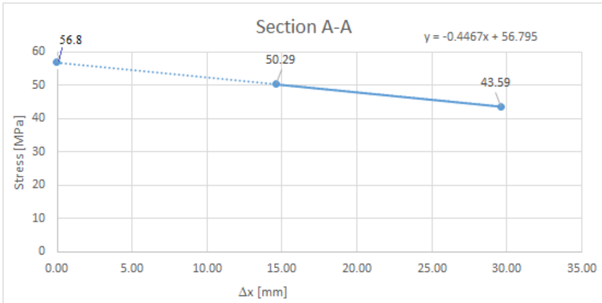

Figure 9: *Determination of stress read out points and hot spot stress, Major Prn. Stress value, Section A-A (see Fig.5)*

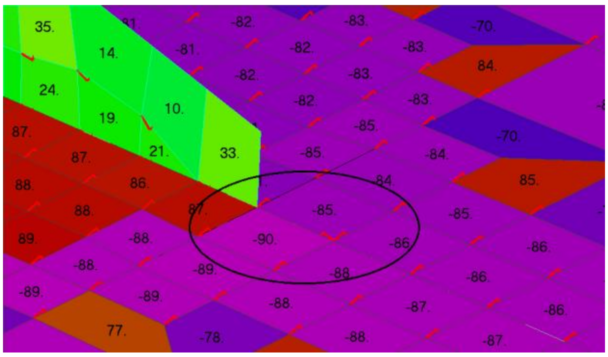

Figure 10: *Plate Top Prn. Stress angle, LC-S1*

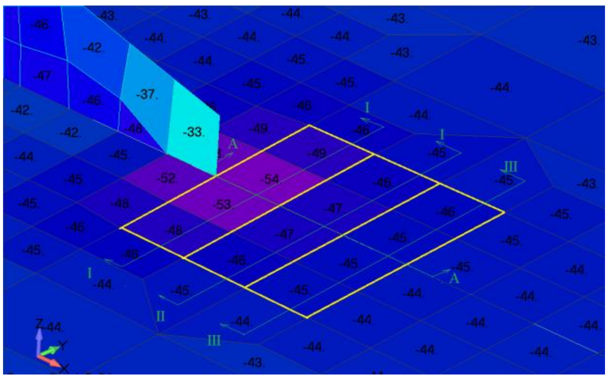

Figure 11: *Environmental stress for weld seam fatigue check, Minor Prn. Stress, LC-S1*

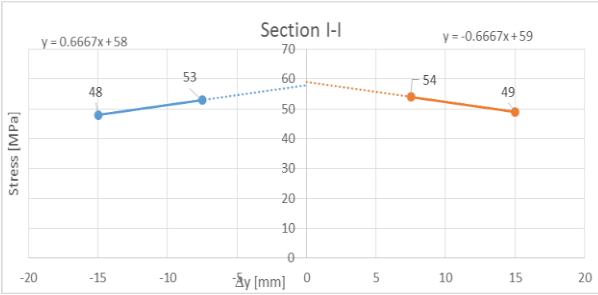

Figure 12: *Linear extrapolation curve for upper surface based on element centre point, Major Prn. Stress value, Section I-I (see Fig.11)*

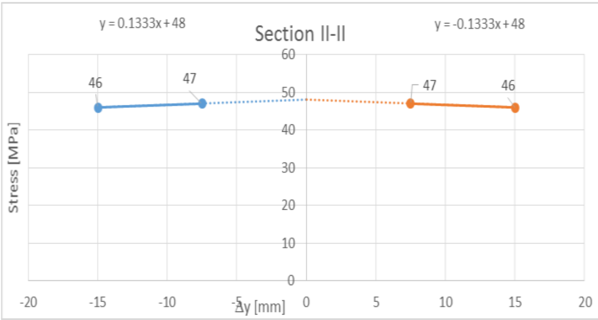

Figure 13: *Linear extrapolation curve for upper surface based on element centre point, Major Prn. Stress value, Section II-II (see Fig.11)*

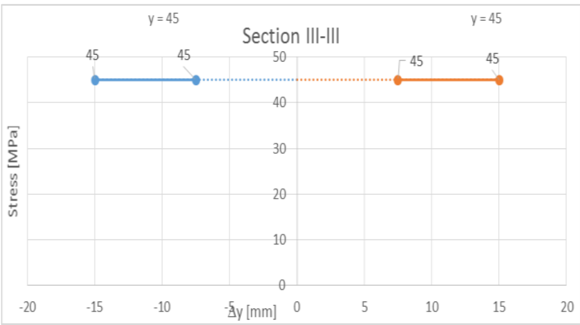

Figure 14: *Linear extrapolation curve for upper surface based on element centre point, Major Prn. Stress value, Section III-III (see Fig.11)*

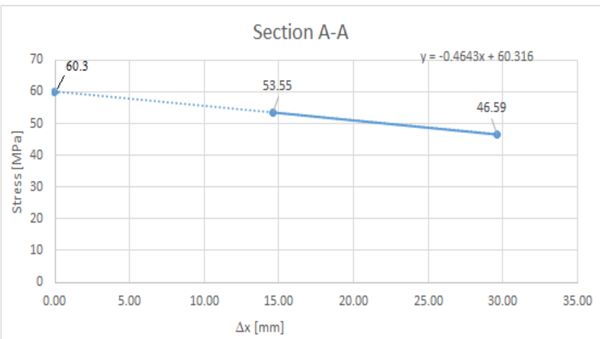

Figure 15: *Determination of stress read out points and hot spot stress, Major Prn. Stress value, Section A-A (see Fig.11)*

The Major Prn. Stress values away from the intersection line is $\sigma_{\text{Major Prn. stress}}$ = 56.8 MPa (see Fig. 9) for loading case LC-H1 and the Minor Prn. Stress values away from the intersection line for loading case LC-S1 is $\sigma_{\text{Minor Prn. stress}}$ = -60.3 MPa (see Fig. 15).

The hot spot stress value has been obtained:

$\Delta\sigma_{HS} = \sigma_{\text{Major Prn. stress}} + |\sigma_{\text{Minor Prn. stress}}| = 56.8 + 60.3 = 117.1$ MPa and this value was used to calculate the fatigue life of the weld seam. Using the above methodology it was determined the environmental fatigue damage (D_{Env}) presented in Table 3.

Table 3: *The environmental fatigue damage*

$\Delta\sigma_{Env}$ N/mm^2]	D_{Env}	Fatigue life [year]	DFF	η= 1/DFF	Status $D_{Env} \leq \eta$
117	0.19	**63**	2	0.5	OK

In conclusion, the fatigue life for the equipment supporting structure integration is found to be acceptable.

References

1. [Det Norske Veritas, 2018], DNV-RP-C203, *Fatigue Design of Offshore Steel Structures*, 2018.
2. [Det Norske Veritas, 2018], DNV CN 30.7, *Fatigue Assessment of Ship Structures*, 2018.
3. [Brebbia, 2013] C.A. Brebbia, S. Walker *Dynamic analysis of offshore structures*, 2013.
4. [Lotsberg, 2006], Inge Lotsberg and Gudfinnur Sigurdsson *Hot Spot Stress S-N Curve for Fatigue Analysis of Plated Structures*, Journal of Offshore Mechanics and Arctic Engineering, 2006.
5. [Dong , 2012], Wenbin Dong, Torgeir Moan, Zhen Gao, *Fatigue reliability analysis of the jacket support structure for offshore wind turbine considering the effect of corrosion and inspection*, Reliability Engineering & System Safety, 2012.