GMO Journal of Ship and Marine Technology Journal
Volume: 218, December 2020
ISSN: 1300-1973, e-ISSN: 2651-530X, Journal homepage: http://www.gmoshipmar.org/

LNG Gemisinin Tekne Boyuna Giden Yapısal Eleman Bağlantılarının Basitleştirilmiş Yorulma Mukavemeti

Özgür Özgüç [1]

[1] İstanbul Teknik Üniversitesi, İstanbul, Türkiye

ozguco@itu.edu.tr, ORCID: 0000-0002-7238-0642

ÖZET

Yorulma mukavemeti konusu, gemi inşa endüstrisindeki gemi sahipleri, tersaneler, tasarımcı ve Klas kuruluşları için her zaman kritik olmuştur. Yorulma analizleri için hesaplama prosedürleri karmaşık ve zaman alıcı bir iştir, ancak güvenli operasyon amaçlı çok kritik bir öğedir. Bu çalışmanın temel amacı, bir LNG gemisinin DNVGL Klas 30.7: “Gemi Yapılarının Yorulma Değerlendirmesi” ne dayanan basitleştirilmiş yorulma mukavemeti yöntemini kullanarak bir vaka çalışması üzerinde boyuna giden yapısal elemanların yorulma ömrünü tahmin edebilmektir. Ful yükleme durumu ve balast durumu, yorulma hasarı değerlendirmesine göre incelenir. Yorulma ömrü, Kuzey Atlantik deniz ortamlarında seçilen dinamik dalga ortamı ve 25 yıllık bir tasarım ömrü için hesaplanır. İncelenen detaylarının çoğu için, yorulma ömürleri 15 yıllık verimli bir korozyon ömrü kullanılarak 25 yılın üzerindedir. Bununla birlikte, dip yapı, alt cidar ve alt hopper levhasının çerçevelerine uzunlamasına bağlantıların, 25 yılın altında bir yorulma ömrünü göstermektedir. Geminin tüm ömrü boyunca etkin bir korozyon kaplama sağlanırsa, boyuna giden stifner bağlantılarının sadece alt tarafı ve üst hopper kısmı modifikasyonlara gereksinim duyuyor. Yorulma ömürleri 25 yıldan az olan yapısal detayların onarım yöntemleri bir öneri şeklinde bu çalışmanın sonunda sunuluyor.

Anahtar kelimeler: Yorulma hasarı, S-N yorulma eğrileri, LNG gemisi, yorulma nedenli çatlak, onarım önerisi.

Makale geçmişi: Geliş 25/07/2020 – Kabul 03/10/2020

GMO Journal of Ship and Marine Technology Journal
Volume: 218, December 2020
ISSN: 1300-1973, e-ISSN: 2651-530X, Journal homepage: http://www.gmoshipmar.org/

Simplified Fatigue Assessment of Hull Longitudinals Connections of an LNG Vessel

Özgür Özgüç [1]

[1] Istanbul Technical University, Istanbul, Turkey

ozguco@itu.edu.tr, ORCID: 0000-0002-7238-0642

SUMMARY

The problem of fatigue has been very critical for ship owners, designer, classification society etc. in shipbuilding industry. The assessment procedure for fatigue strength is complicated and a time-consuming job, but, for the maintenance purpose, it is a very critical item. Main target of present study is to calculate the fatigue life of longitudinal members amidships, where an LNG vessel is addressed as a case study using simplified fatigue method, which is based on DNVGL Classification Note 30.7: "Fatigue Assessment of Ship Structures". A full load condition and a ballast condition are investigated with respect on fatigue damage assessment. Fatigue life is computed for selected longitudinal connections, amidships and 25-year designed life is aimed with North Atlantic wave environment. For the most of the details examined, the fatigue lives are found above 25 years using an efficient coating life of 15 years. The lower side, bottom and hopper plate longitudinal connections to web frames indicate fatigue lives below 25 years. If an effective coating is maintained during the entire lifetime of the vessel, only lower side and lower part of hopper plate longitudinal connections at web frames would need modifications. Repair proposals are given for those details having fatigue lives less than 25 years in the end of the study.

Keywords: Fatigue damage, S-N fatigue curves, LNG carrier, fatigue crack, repair proposal.

Article history: Received 25/07/2020 – Accepted 03/10/2020

1. Introduction

Fatigue damage is the most common damage in ship structures due to cyclic wave loads. Fluctuating stresses arising from wave loads can initiate fatigue cracks in the vicinity of joints which are inadequately designed, constructed and maintained. When the critical areas with respect to fatigue are identified, it is time to select the fatigue calculation method. The methods range from a simplified method based on simplified analytical expressions to refined numerical simulations. Depending on the detail to be considered and requested accuracy of the calculations, three fatigue analysis options are mainly used such as simplified method, component stochastic and full spectral method.

The simplified fatigue calculation option is suitable for members where the total stress response can be defined as a sum of individual stress components due to global wave bending moments, external and internal local pressures. Typical details are stiffeners and plating. The wave loads are computed using Class Rule formulas and stress response is calculated by simplified approaches using beam theory in conjunction with tabulated values of stress concentration factors (Ozguc, 2016).

Fatigue is important designing criteria for ships to ensure a sufficiently high safety level. It is known that the fatigue strength decreases in corrosive environment and many experiments were carried out to comprehend the decrease in fatigue strength in corrosive environment (Ozguc, 2017a)

The results of fatigue assessment are influenced by several aspects of cost and safety, including the quality of connection materials, quality of welding fabrication, frequency of inspections and repairs, consequences of potential fatigue failure, and residual strength of partially damaged structural systems (Ozguc, 2017b and 2017c). An overview of some recent developments on the aging effects on the structural integrity of ships was addressed by Jurišić et al. (2017).

The occurrence of cracks in the hull structure of oil and gas carriers is a major concern for the marine industry because the crack propagation will reduce the collapse strength of the stiffened panels and consequently decrease the ultimate hull girder capacity of ship structures (Garbatov et al. 2016). Classification Societies developed different tools to ensure a high-quality standard of ageing vessels. The computer programs and procedures available today are sufficient to avoid most fatigue problems associated with ship shaped structures (Kyungseok 2013). An example of a more rigorous procedure by means of DNVGL Nauticus Hull and Sesam program packages (DNVGL, 2007) was presented, where a simplified method was used in accordance with Class Rules for ships.

Corrosion and fatigue cracks are the most siginificant degradation effects of ship structures. Both of the aging effects have strong implications for virtually all related failure modes, such as rising stress levels and weakening ship structural strength. A very large crude oil carrier's corrosion-related impact on a ship's hull was investigated and analyzed by Van and Yang (2017).

The fatigue assessment of the deck longitudinals of oil carriers was investigated by Parunov et al. (2013). An assessment of stress intensity factors and the Paris-Erdogan law were defined in a parametric expression. During the inspection of two tanker vessels, long-term corrosion effects were modelled in accordance with the regression equation fit for measuring thickness. The value of the governing parameters of crack propagation was studied in parametric studies. A comparison was produced with fatigue experiments carried out by means of linear mechanics of fracture and S-N approaches.

Fatigue damages reduce the load-carrying capacity of the structure, and may result in leakages, resulting in pollutions, and cargo mixing in confined areas in severe cases, and such structural damage may conceivably cause catastrophic failure or total loss of the units. Hull longitudinals are essential structural elements in the side shell structure of floaters. The wave loads introduce significant dynamic stresses in the side shell below the mean water level. This has led to a number of fatigue cracks in the welded connections between side longitudinal stiffeners and transverse frames and bulkheads (Ozguc, 2018a and 2018b).

Lotsberg (2019) has provided an overview of the evolution over the past 40 years of fatigue quality requirements for marine structures. The construction of offshore structures in harsh environments like the North Sea in the 1970s called for fatigue quality requirements for ship and offshore structures. The need for fatigue design of ship structures became increased as more high strength steel was being used in these structures during the 1970s.

Ozguc (2020a and 2020b) generated Finite Element (FE) models for a typical midship section between two transverse bulkheads in order to determine relative deflection between a transverse frame and a transverse bulkhead due to external sea pressure and internal loads from tanks. The assumptions made in the analyses might differ from those governing the fatigue life of specific vessels. The findings of structural analyses provided remaining life assessment, inspection plan definition based on hot-spot maps, determination of repair and modification solution such as avoiding further cracking, ensure sufficient corrosion margin, and avoiding integrity issues resulting in production down time and hot work or dry dock (Ozguc, 2020c).

The fatigue damage is a potential for the structural safety of ship structures and accurate prediction of fatigue crack propagation, and its impact on the integrity of the ships are crucial. Ozguc (2020d) conducted this task and achieved ensuring the safety of ship structures with fatigue life extension of the upper and lower hopper knuckle connection at an oil tanker by modifying properly the structural layout of the configuration.

Ozguc (2020e) described fatigue analysis procedures that were supported by a developed tool to be used in the calculations. Three details of local fine mesh models such as deck erection butt weld, longitudinal stiffener through web-frame, and bottom erection butt weld were analyzed. The results were compared with the component-based approach.

Main goal of current study is to report the calculated fatigue life of longitudinal members amidships, where a LNG vessel is addressed as a case study using the simplified fatigue method, which is based on DNVGL Classification Note 30.7: "Fatigue Assessment of Ship Structures". A full load condition and a ballast condition are investigated with respect on fatigue damage assessment. Fatigue life is calculated for the selected longitudinal connections amidships and 25-year design life is aimed in North Atlantic wave environment. For the most of the details examined, the fatigue lives are found above 25 years using an efficient coating life of 15 years. The lower side, bottom and hopper plate longitudinal connections to web frames show the fatigue lives below 25 years.

2. Fatigue Calculation Method

The fatigue life may be computed based on the S-N fatigue approach under the assumption of linear cumulative damage (Palmgrens-Miner rule). Fatigue calculations are carried out based on DNVGL Classification Note 30.7: "Fatigue Assessment of Ship Structures". To calculate fatigue lives of longitudinals (also referred to as stiffeners) connected to web frames and transverse bulkheads. A brief explanation of the calculation procedure is provided as follows;

- Loads (transfer functions) are taken from the hydrodynamic analysis.
- Fatigue damage is calculated on basis of the Palmgrens-Miner rule, assuming linear cumulative damage.
- North Atlantic wave data are applied according to DNVGL CN 30.7. Short crested waves with a wave spreading function cos2, a constant wave directional distribution and Pierson Moskowitz wave spectrum are used.
- A vessel speed of 13 knots, corresponding to 2/3 of design speed is used.
- 12 headings with 22 periods for each heading has been used.
- The target life is set to 25 years
- The S-N Curve I (Welded joint, Air or Cathodic protection), is used for the deck.

- Both S-N Curve II (Welded joint, Corrosive Environment) and SN Curve I, is used for details in the ballast tanks. Fatigue damage both for coated and uncoated ballast tanks are calculated.
- The fraction of time at sea has been taken as 0.85 (0.45 in full load and 0.40 in ballast).
- Stress reduction factor, fm = 0.85, due to mean stress effect is included (assumed zero mean stress).

3. Load Transfer Function

The fatigue calculations are in accordance with the transfer functions determined in hydrodynamic analysis. The linear mode of the wave load program DNVGL WASIM (2009) calculates the dynamic pressures below the waterline. In order to include the effect of intermittent wet and dry surfaces, pressure is reduced above Tact – zwl, using the factor rp, as seen in Figure 1. The external dynamic pressure amplitude, pe, related to the draught of the load condition considered, is taken as:

$$p_e = r_p . p_d \quad (1)$$

Where p_d : dynamic pressure amplitude calculated by DNVGL WASIM

r_p : reduction and extrapolation of the pressure amplitude in the surface zone

$r_p = 1.0$ for $z < T_{act} - z_{wl}$

$r_p = \dfrac{T_{act} + z_{wl} - z}{2z_{wl}}$ for $T_{act} - z_{wl} < z < T_{act} + z_{wl}$

$r_p = 0.0$ for $T_{act} + z_{wl} < z$

z_{wl} : height of dynamic wave pressure, measured from actual water line

$$z_{wl} = \frac{3}{4}\frac{p_{dT}}{\rho g} \quad (2)$$

p_{dT} : dynamic pressure at 10^{-4} probability level at $z = T_{act}$

T_{act} : the draught in the considered load condition

ρ : density of sea water = 1025 kg/m^3

z : distance from B.L. to considered point

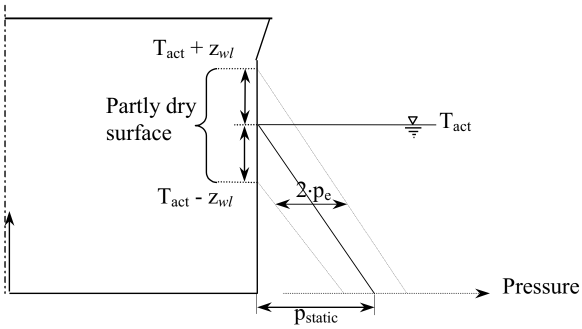

Figure 1. Reduced pressure range in the surface region (DNVGL CN 30.7).

4. Stress Concentration Factors

The fatigue life of a detail is governed by the notch stress range. For components, other than smooth specimens, the notch stress is obtained by multiplication of the nominal stress by K-factors. The K-factors in this study are described as follows:

$$K = \frac{\sigma_{\text{notch}}}{\sigma_{\text{nominal}}} \tag{3}$$

The relation between the notch stress range to be used together with the S-N-curve and the nominal stress range is:

$$\Delta\sigma = K \cdot \Delta\sigma_{\text{nominal}} \tag{4}$$

All stress risers have to be considered when evaluating the notch stress. This can be done by multiplication of K-factors arising from different causes. The resulting K-factor to be used for calculation of hot spot stress is derived as:

$$K = K_g \cdot K_w \cdot K_{te} \cdot K_{t\alpha} \cdot K_n \tag{5}$$

Where, K_g : stress concentration factor due to the gross geometry of the detail considered

K_w : stress concentration factor due to the weld geometry. K_w=1.5 if not stated otherwise

K_{te} : additional stress concentration factor due to eccentricity tolerance (normally used for plate connections only)

$K_{t\alpha}$: additionally stress concentration factor due to angular mismatch (normally used for plate connections only)

Kn : additional stress concentration factor for asymmetrical stiffeners on laterally loaded panels, applicable when the nominal stress is derived from simple beam analyses.

5. Unit Stress Factors

The load-stress-relation is calculated independently for loads such as global vertical bending, global horizontal bending, Local bending of laterally loaded stiffener and plate, and Shear in stiffener lug. The calculations are based on unit loads.

5.1. Global bending

$$A_{VBM/HBM} = K_W K_a \cdot \frac{M_w}{I} \cdot (z - z_{N.A.}) \tag{6}$$

where: K_a : Stress concentration factor for axial stress

M_w : Wave induced bending moment, vertical or horizontal

z : Distance from BL or CL to the considered point

$z_{N.A.}$: Height of neutral axis, measured from BL or CL

I : Moment of inertia

5.2. Local bending of stiffeners

The load-stress-relation for local bending of stiffeners are calculated as:

$$A_P = K_w K_b \cdot K_n \cdot \frac{M}{Z_s} \quad \text{for unit pressure} \tag{7}$$

where K_b : stress concentration factor for local bending

K_n : stress concentration factor of laterally loaded unsymmetrical stiffeners

M : bending moment per unit pressure at stiffener support adjusted to the hot spot position

Z_s : section modulus of stiffener

The bending moment is calculated as:

$$M = \frac{sl^2}{12} r_p \tag{8}$$

Where, s : stiffener spacing

l : effective span of longitudinals

r_p : moment interpolation factor for interpolation to hot spot position

5.3. Shear in stiffener lug

The principal stress amplitude due to the shear force in the stiffener web-frame-connection is:

$$A_{SP} = K_q \cdot \frac{Q}{A_s} = K_q \cdot \frac{sl}{A_s}$$

(9)

Where, A_s : stiffener connection area

K_q : total stress concentration factor based on nominal shear stress in stiffener connection area and notch stress in lug/frame.

6. S-N Curves

The S-N curves are in accordance with Paris-Erdogan rule, which are the mean minus two-standard-deviation curves for relevant experimental data, and thus associated with a 97.6% probability of survival. For deck plating S-N curve I, for welded joints in air is applied in the calculation of the fatigue damage. The S-N parameters are listed in Table 1. The S-N curve II, for welded joints in corrosive environment is applied in the calculation of the fatigue damage for stiffeners. The S-N parameters are given in Table 2.

Table 1. S-N Parameters Curve I (DNVGL CN 30.7)

Cycles	Log(a)	m
$N \leq 10^7$	12.65	3
$N > 10^7$	16.42	5

Table 2. S-N Parameters Curve II (DNVGL CN 30.7)

Cycles	Log(a)	m
All	12.38	3

7. An LNG Vessel

The main particulars of LNG vessel are presented in Table 3.

Table 3. LNG vessel main particulars

Length overall, L_{OA}	287.00	m
Length between perpendiculars, L_{PP}	275.00	m
Breadth, B	44.00	m
Depth, D	26.80	m
Draught, T (in design)	12.10	m

Two load conditions are being analysed, which are load condition LC (1), ballast condition departure with 100% consumables LC (2). The main characteristics for the loading conditions are presented in Table 4.

Table 4. Analysed loading conditions

Load Condition	Draught AP [m]	Draught FP [m]	Displ. [Tonnes]	C.O.G. from AP [m]	KG [m]	GM [m]	Roll Radius [m]	Pitch Radius [m]
LC (1)	9.903	9.903	82007.6	138.246	11.985	9.869	16.72	69.07
LC (2)	11.856	11.856	98102.3	137.168	15.882	4.399	13.78	64.56

8. The Hot-spots Examined in Fatigue Damage

A length between web frames of 3200 mm and a stiffener spacing of 800 mm is applied in the calculations. Some of the stiffener have supporting brackets on top of the stiffener at the web frame. The hot spot is located in the toe and heel of the supporting bracket as shown in Figure 2. The combined stress response is calculated as the combination of global hull girder bending and local bending of laterally loaded stiffener. All other stiffeners are attached to the web frame by non-tight collar plates. The hotspot of these stiffeners is located in the lug as shown in Figure 3. The total stress response is calculated based on the shear stress in the lug due to lateral loading of the stiffener, and the combination of global hull girder bending and local bending of laterally loaded stiffener. The two effects are not combined. Fatigue calculations are also performed for general deck details. The total stress response is calculated as the combination of global horizontal and vertical bending.

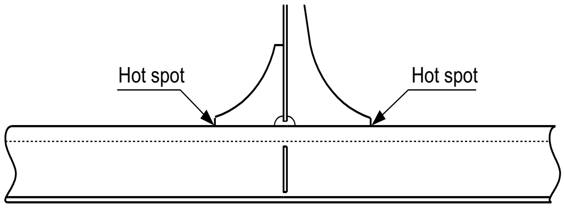

Fig. 2. A typical hot-spots for stiffeners with supporting bracket (Ozguc, 2016).

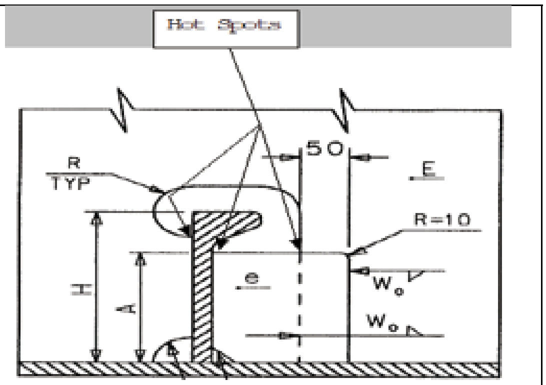

Fig. 3. A typical hot-spots for non-tight collar plate attachment (Ozguc, 2016).

9. Fatigue Assessment Results

The calculated fatigue damages are based on a design life of 25 years and the associated fatigue lives are summarized in Table 5 and Table 6. The total fatigue damage is calculated as:

$$D_{total} = D_{Full} + D_{Ballast} \tag{10}$$

Fraction of time in loaded and ballast condition is assumed to be 0.45 and 0.4 respectively. From the calculated fatigue damage, the fatigue life is given as:

$$FatigueLife = \frac{FatigueDesignLife}{D_{total}} = \frac{25}{D_{total}} \tag{11}$$

Table 5. Calculated fatigue damage and associated fatigue life for longitudinal stresses

Detail	**SCF**		**Uncoated**		**15 year effective coating**		**Coating all lifetime**	
	K_wK_g *	**K_n**	**Damage**	**Fatigue life**	**Damage**	**Fatigue life**	**Damage**	**Fatigue life**
Frames with brackets								
B-10	1.875	1.0	1.0	**24**	0.7	34	0.4	67
B-23	1.875	1.0	1.0	26	0.7	34	0.4	71
IB-10	1.875	1.0	0.4	58	0.4	67	0.1	194
H-103	1.845		0.5	46	0.4	56	0.2	143
S-28	1.845		1.3	**19**	0.9	28	0.5	50
Frames without brackets								
B-2	1.8	1.0	2.6	**10**	1.4	**18**	1.2	**21**
B-10	1.8	1.0	2.5	**10**	1.4	**18**	1.1	**23**
B-23	1.8	1.0	2.6	**10**	1.4	**18**	1.1	**22**
IB-2	1.8	1.0	1.0	**24**	0.8	34	0.4	58
IB-8	1.8	1.0	1.1	**23**	0.8	32	0.5	55
IB-10	1.8	1.0	1.1	**22**	0.8	31	0.5	53
S-28	1.8 - 1.9	1.4	5.1	**5**	2.0	**13**	2.4	**10**

Detail	SCF		Uncoated		15 year effective coating		Coating all lifetime	
	K_wK_g *	K_n	Damage	Fatigue life	Damage	Fatigue life	Damage	Fatigue life
S-31	1.8 - 1.9	1.4	3.0	**8**	1.5	**17**	1.4	**18**
S-33	1.8 - 1.9	1.3	4.0	**6**	1.7	**14**	1.9	**14**
S-36	1.8 - 1.9	1.3	1.9	**13**	1.2	**22**	0.8	30
S-39	1.8 - 1.9	1.3	0.8	31	0.6	39	0.3	77
H-100	1.8 - 1.9	1.5	2.3	**11**	1.3	**19**	1.1	**23**
H-104	1.8 - 1.9	1.4	2.4	**10**	1.4	**18**	1.1	**23**
H-108	1.8 - 1.9	1.4	1.7	**15**	1.1	**23**	0.7	33
IS-33	1.8 - 1.9	1.4	1.5	**17**	1.0	25	0.6	39
IS-36	1.8 - 1.9	1.3	1.2	**20**	0.9	29	0.5	52
IS-39	1.8 - 1.9	1.3	0.6	41	0.5	50	0.2	128
Bulkheads								
Bx2	2.1	1.0	1.5	**16**	1.0	25	0.6	40
IBx3	2.1	1.0	0.6	41	0.5	52	0.2	127
IBx8	2.1	1.0	0.6	39	0.5	49	0.2	119
Hx103	1.845	1.5	0.8	30	0.6	40	0.3	79
Sx33	1.845	1.3	1.4	**17**	0.9	26	0.6	43
Sx34	1.845	1.3	1.1	**22**	0.8	31	0.4	56
Sx36	1.845	1.3	0.7	35	0.6	45	0.2	106
Sx52	1.845	-	0.3	74	0.3	85	0.1	307
Deck plating								
Plate in deck	2.2	1					0.6	41
Plate in deck	2.4	1					0.9	30

* Axial and bending, B – Bottom, IB – Inner Bottom, H – Hopper Tank, S – Side, x- At BHD (Stiffener Numbers as shown on Midship Section)

Please note that for the frames without brackets fatigue calculations are also calculated for details that have brackets or small length (B-2, B-10, B-23, IB-10, S-28). The calculations have been performed for relative regular steps in order to have an overall picture of where the fatigue life is acceptable or not. Calculations will thus be relevant for the stiffener next to the calculated one.

Table 6. Calculated fatigue damage and associated fatigue life for shear connections (stiffener lug)

Detail	SCF	Full load	Ballast	Total Fatigue Damage	Calculated Fatigue Life
	K_wK_g	Damage	Damage	Damage	Years
S-33	6.9	0.23	0.18	0.41	62
S-34	6.9	0.16	0.12	0.28	90
S-36	6.9	0.08	0.04	0.12	>100
S-41	6.9	0.00	0.00	0.00	>100

Fatigue calculations are performed for one cross-section amidships and at nearest bulkhead. The location and fatigue lives of the selected details are demonstrated in Figure 4.

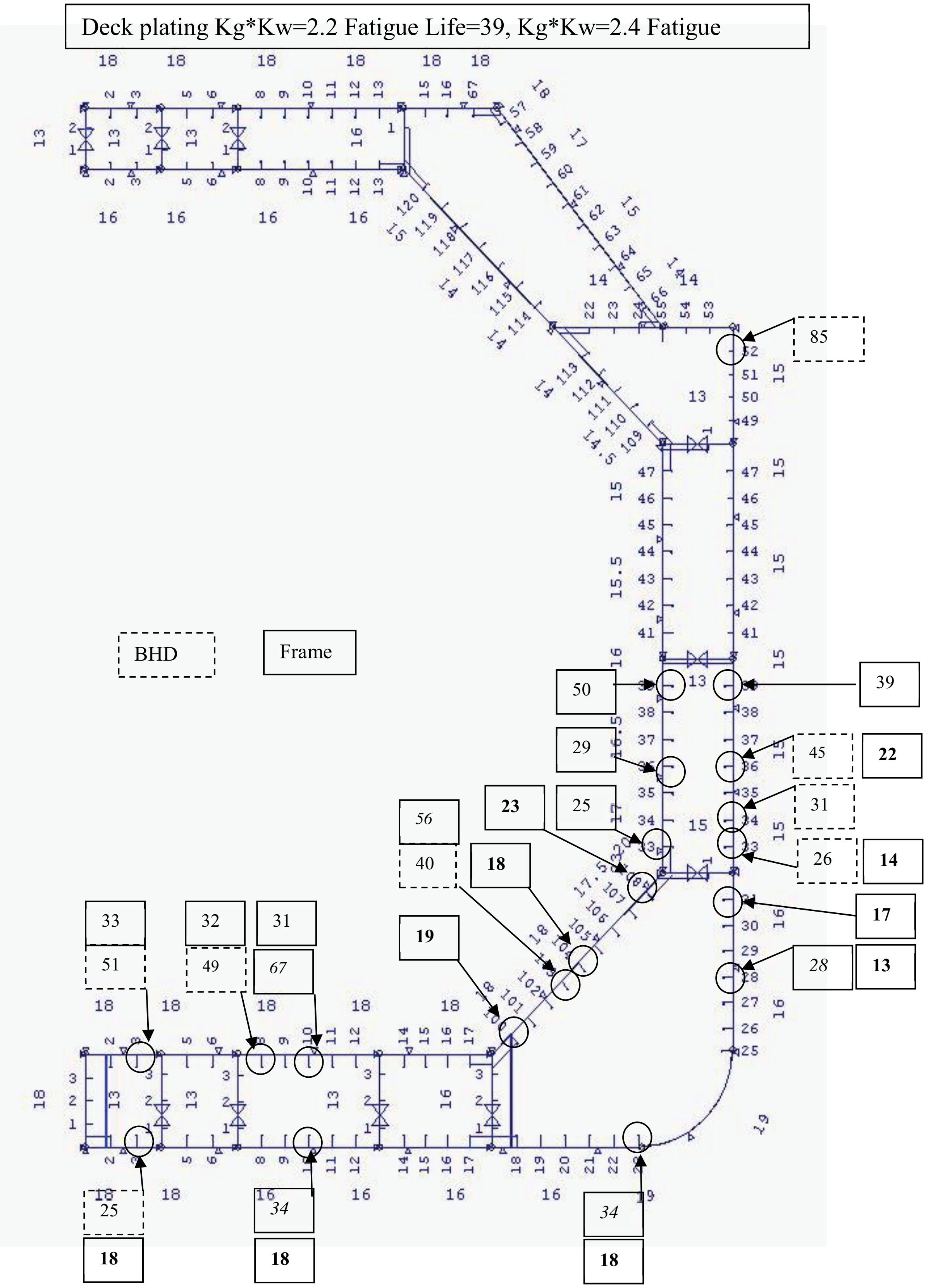

Fig. 4. Fatigue lives of details considered in the fatigue assessment, 15 years effective coating (*italic shows* frames with existing brackets).

10. Concluding Remarks

The concluding remarks from present study can be drawn as follows;

Frames – assuming uncoated condition:

- Stiffeners with brackets (B-10, B-23, IB-10, H-103, S-28) show fatigue lives above 25 years.
- Stiffeners in bottom without brackets show fatigue lives below 25 years.
- Stiffeners in inner bottom without brackets show fatigue lives above 25 years in uncoated condition.
- Stiffeners in hopper plate without brackets show fatigue lives below 25 years.
- Stiffeners in inner side show fatigue life above 25 years in uncoated condition.
- Stiffeners in outer side show fatigue lives below 25 years for stiffeners below stiffener S-37.
- The deck area is assumed to be in a non-corrosive environment.

Frames – assuming 15-years effective coating:

- Stiffeners with brackets (B-10, B-23, IB-10, H-103, S-28) show fatigue lives above 25 years.
- Stiffeners in bottom without brackets show fatigue lives below 25 years. Stress concentration factors according to bulbs connected to frames with lugs are used. This is conservative, but fatigue lives are expected to be below 25 years for the actual detail.
- Stiffeners in inner bottom without brackets show fatigue lives above 25 years.
- Stiffeners in hopper plate without brackets show fatigue lives below 25 years.
- Stiffeners in inner side show fatigue life above 25 years.
- Stiffeners in outer side show fatigue lives below 25 years for stiffeners below stiffener ~S-35. These stiffeners have to be modified.
- The deck area is assumed to be in a non-corrosive environment.

Frames – assuming 25-years effective coating:

If effective coating is maintained during the entire 25 years' design life, only lower side longitudinals and hopper plate longitudinals show fatigue lives below 25 years. The conservative assumption used for the bottom longitudinals probably leads to fatigue lives above 25 years.

Bulkheads:

The bulkheads show fatigue lives below and above 25 years for uncoated condition. For coated condition, all fatigue lives are above 25 years. Relative deflection is not included in the calculations. This will affect the results in bottom and side. It may be advisable to increase bracket size and apply soft nose brackets at all locations.

Shear connections (stiffener lug details)

For shear connections, there are some effects that are not accounted for in the calculations since they require a more comprehensive study by means of local FE analysis. Such effects are:

- *Web Frame Bending:* The web frame bending will cause tensile and compressive stresses at the hot spot locations. This is not evaluated.

- *Web Frame Shear:* Web frame shear will either counteract or amplify the shear stress depending on the stress direction, and the consequence of this effect should be further investigated.
- *Relative Deflection:* Relative deflections between web frames will produce additional shear forces in the stiffeners and rotation of the stiffeners in the web connection. The stress due to relative deflection will superimpose stresses due to local lateral loading of the stiffener. Rotation of the stiffener will lead to through thickness bending of the lug and web frame and thereby influence the hot spot stress.

Double bottom stresses are not included in the fatigue calculations, but is not expected to influence the results significantly.

The fatigue damage for lug connection depends on the actual geometry of the detail. The stress concentrations used are based on details as defined in DNVGL CN 30.7. Note that the bending moment decreases towards the ends such that 40 m away from midship in either direction the vertical bending moment is 20% lower than amidships. This will affect the fatigue damage at bottom/deck longitudinals. For the deck, all stresses arise from hull girder bending moment, and for the bottom large parts of the stress arise from hull girder bending moments. The fatigue damage will consequently decrease towards the ends for these parts.

For those areas where stresses mainly are caused by local internal or external pressure, the situation is opposite as both external pressures and accelerations normally increase towards the ends. The fatigue damage may consequently increase away from amidships. The fatigue strength of the longitudinals subjected to lateral loading attached to the web frames by nontight collar plates may be improved by modifying the geometry of the lug and web cut-out as shown in Figure 3. This will reduce the stress concentration factor in the order of 1.3. As an approximation (conservative), the fatigue life is inverse proportional to the stress raised to the power of 3 and hence the fatigue life will be increased by a factor in the order of 2.

For stiffeners with fatigue life below 25 years it is advised that supporting brackets with soft nose are fitted at the web frames since stiffener rotation at the web frame will cause large stresses due to through thickness bending at the hot spot of the lug. Such brackets will significantly reduce the stress response in the lug and web frame and in most cases, move the critical hot spots to the bracket toe and heel. Typical positions are at transverse bulkheads, web frames adjacent to transverse bulkheads and web frames where the distance to the adjacent frame aft is different to the adjacent frame forward. Specific positions are lower side where the fatigue life is low. A suggested bracket design with double-sided soft nose brackets having 600mm breadth with 500 and 600mm radius and is shown in Figure 5.

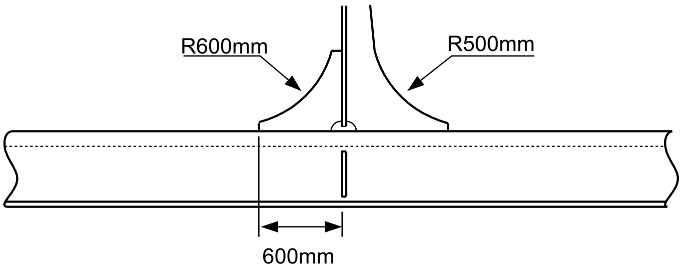

Fig. 5. Proposed bracket design.

In conclusion, the findings of the analyses provide remaining life evaluation, inspection plan definition based on hot-spot maps, determination of repair and modification solution such as avoiding further cracking, ensure sufficient corrosion margin, and avoiding integrity issues resulting in production down time and hot work or docking activities.

11. References

Det Norske Veritas (DNVGL) Rules for Classification of Ships, Pt. 3 Ch. 1, Hull structural design ships with length above 100 meters, July 2014.

DNVGL Classification Note 30.7. Fatigue Assessment of Ship Structures, September 2012.

DNVGL Nauticus Hull, Nauticus Hull User Manual: “Fatigue”, Fatigue Assessment, Simplified Method, January 2007.

DNVGL SESAM User Manual - WASIM. (2009). Wave Loads on Vessels with forward Speed, DNVGL Software Report.

Garbatov, Y., Rodopoulos, C., and De Jesus, A. (2016). Fatigue strength assessment of ship structures accounting for a coating life and corrosion degradation. International Journal of Structural Integrity.

Kyungseok, L. (2013). Simplified fatigue guideline for deck opening and outfitting supports, Ships and Offshore Structures, 8:2, pp. 154-162.

Ozguc, O. (2016). Fatigue assessment of longitudinal stiffener end connections for ageing tankers. Journal of Offshore Structure and Technology. 3(1): 1–12.

Ozguc, O. (2017a). Fatigue assessment of longitudinal stiffener end connections for ageing bulk carriers. Journal of Marine Science and Technology, 25(5), 543-551.

Ozguc, O. (2017b). Evaluation of different trading routes on fatigue damage for a 216K m3 LNG carrier. Journal of Marine Science and Technology, 25(4), 458-463.

Özgüç, Ö. (2017c). Typical cracks in deck of ship-shaped structures and ways to modify and improve the design. Sakarya Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 21(5), 759-768.

Ozguc, O. (2018a). Simplified fatigue analysis of structural details of an ageing LPG carrier. Journal of Marine Engineering and Technology, 17(1), 33-42.

Özgüç, Ö. (2018b). Global fatigue assessment for deepwater semi-submersible. GMO Journal of Ship and Marine Technology, 24(214), 37-53.

Ozguc, O. (2020a). A new risk-based inspection methodology for offshore floating structures. Journal of Marine Engineering & Technology, 19(1), 40-55.

Ozguc, O. (2020b). Fatigue assessment of FPSO hull side shell longitudinals using component stochastic and full spectral method. Applied Ocean Research, 101. DOI: 10.1016/j.apor.2020.102289.

Ozguc, O. (2020c). Conversion of an oil tanker into FPSO in Gulf of Mexico: strength and fatigue assessment. Ships and Offshore Structures, 1-19. DOI: 10.1080/17445302.2020.1790298.

Ozguc, O. (2020d). Efficient fatigue assessment of the upper and lower hopper knuckle connections of an oil tanker. Proc IMechE Part M: J Engineering for the Maritime Environment, DOI: 10.1177/1475090220945460.

Ozguc, O. (2020e). Procedures of fatigue analysis by supporting direct load application on midship sections. Transactions on Maritime Science, 9(1), 6-22.

Parunov, J., Gledić, I., Garbatov, Y. Y., & Guedes Soares, C. (2013). Fatigue assessment of corroded deck longitudinals of tankers. International journal of maritime engineering, 155(PART A), pp. 9-21.
Lotsberg, I. (2019). Development of fatigue design standards for marine structures. Journal of Offshore Mechanics and Arctic Engineering, 141(3).

Van, T. V., and Yang, P. (2017). Effect of corrosion on the ship hull of a double hull very large crude oil carrier. Journal of marine science and application, 16(3), 334-343.

Jurišić, P., Parunov, J., & Garbatov, Y. (2017). Aging effects on ship structural integrity. Brodogradnja: Teorija i praksa brodogradnje i pomorske tehnike, 68(2), 15-28.