Comparative Study of Spectral Fatigue Life Prediction of LCT Bottom and Deck Bracket

M. Nurul Misbah[1], Septia Hardy Sujiatanti[1], and Raja Andhika Rizki Ramadhani[1]
[1]Department of Naval Architecture, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

Keywords: Spectral Fatigue, LCT Bottom, Deck Bracket

Abstract: Many LCT ships are converted into passenger ship. The ship is operated and encountered cyclic loading. The cyclic loading is a vertical bending moment and the horizontal bending moment that randomly applied through the wave. These bending moments will affect a structural detail to have fatigue. Since these cyclic loadings are continuously applied and endangered the safety of the ship, then the calculations of fatigue are needed. Analysis of fatigue capacity using spectral fatigue is taking the variation of headings, load cases and wave spectrum for each sea state. Headings are started from head sea to the following sea with 45° increment which are represented headings while the ship is undergoing. The load cases are divided into the full load and full ballast condition. Wave spectrum is varied and started form 1 m significant wave height to 2,5 m significant wave height with 0,5 m increment and 5 s to 7 s with increment 1 s for zero-up crossing period. The analysis result is showing that maximum stress of the ship occurred at heading 135° or quartering sea. Based on the analysis result, the fatigue life of the ship will be 28 years and 22 years.

1 INTRODUCTION

The ship which located in waters will run into motion dynamics caused by height and period of the wave. This motion dynamic resulted in cyclic loads. Cyclic loads will result in fatigue in a ship structure. An analysis of fatigue is needed to guarantee the safety of the ship. One of many methods to predict fatigue of a ship structure is spectral fatigue with finite element analysis. This fatigue capacity analysis will be developed to the fatigue life of a ship structure as a safety parameter for operation.

This research is carried out to perform technical calculations of fatigue analysis. These technical calculations are wave spectrum, structure responses due to wave, stress at a remote area and fatigue life analysis. This research used spectral fatigue method. Spectral fatigue method is a method by using a statistical approach.

2 LITERATURE REVIEWS

Each sea has its characteristics depend on nature condition. Sea wave affected by its depth. Therefore, wave's form and characteristic are very complex to explain. Wave basically are differentiated into two types, sinusoidal and trochoidal. These type of waves have its complexity so the calculation to determine actual condition need an approach to visualize character of waves (Bhattacharyya, 1987). These statements are formulated in equation (1).

$$T_z = 2\pi\sqrt{\frac{m_0}{m_2}} \qquad (1)$$

Where,
Tz = period zero up crossing (s)
m0 = spectral moment 0th order
m2 = spectral moment 2nd order.

Wave scatter diagram is a table which has a correlation between significant wave height (Hs) and zero-up crossing period (Tz) and notated with a number of wave incidents. Each table can be translated by one short-term wave analysis (ABS, 2016).

Misbah, M., Sujiatanti, S. and Ramadhani, R.
Comparative Study of Spectral Fatigue Life Prediction of LCT Bottom and Deck Bracket.
DOI: 10.5220/0008375200910096
In *Proceedings of the 6th International Seminar on Ocean and Coastal Engineering, Environmental and Natural Disaster Management (ISOCEEN 2018)*, pages 91-96
ISBN: 978-989-758-455-8

2.1 Wave Spectrum

Measured wave data is represented in form of wave spectrum for further analysis. These spectrums are represented to each sea-state. The wave spectrums which are used for analysis have two parameters that are significant wave height (Hs) and zero-up crossing period (Tz). These spectrums can be presented in the Pierson-Moskowitz spectrum (ABS, 2016). These spectrums are formulated in equation (2).

$$S_{(PM)} = \frac{Hs}{4\pi}\left(\frac{2\pi}{T_Z}\right)\omega^{-5}\exp\left[-\frac{1}{\pi}\left(\frac{2\pi}{T_Z}\right)^4\omega^{-4}\right] \qquad (2)$$

Where,
S(PM) = Pierson-Moskowitz wave spectrum,
Hs = significant wave height (m),
Tz = zero up crossing period (s),
ω = wave frequency (rad/s).

Hasselmann et al found an additional factor for developed Pierson-Moskowitz wave spectrum. So, JONSWAP's spectrum is Pierson-Moskowitz wave spectrum with peak enhancement factor (Santosa and Setyawan, 2013). The spectrum in eq. (2) can be transformed into equation (3).

$$S_{(JWP)} = S_{(PM)}\gamma^{r} \qquad (3)$$

Where,
S(JWP) = JONSWAP wave spectrum,
γ = peak enhancement which is 2.5,
r = peak enhancement factor.

2.2 Stress

Stresses occur in a ship are generated from many sources. Stress which is caused by wave load can be calculated from bending moments that are caused by wave horizontally and vertically (Misbah, et.al, 2018). Formulation of stress caused by bending moments can be explained by equation (4) to equation (6).

$$\sigma_H = \frac{M_z}{I_{CL}}y \qquad (4)$$

$$\sigma_V = \frac{M_y}{I_{NA}}z \qquad (5)$$

$$\sigma_T = \sqrt{\sigma_H{}^2 + \sigma_V{}^2} \qquad (6)$$

Where,
σ = stress (N/m2),
M = bending moment (Nm),
I = inertia moment of section (m3),
z, y = distance of remote area from the neutral axis or centerline point (m).

Stress analysis was plenteous performed by many naval architects. One of them is strength analysis. Strength analysis is divided into two groups, global and local. For global analysis, Misbah et al, 2018, are performed on longitudinal strength research and compared by BKI rules. The analysis is varied by four load cases that are (a) empty cargo in sagging condition, (b) empty cargo in hogging condition, (c) full cargo in sagging condition, and (d) full cargo in hogging condition. The calculation is performed using finite element analysis. Results showed that generated stress are below the permissible stress that are (a) 72.393 MPa, (b) 74.792 MPa, (c) 129.92 MPa and (d) 132.4 MPa (Ardianus, 2016). While local analysis is performed by Ardianus et al, 2017. Local strength analysis is remoted to transverse bulkhead between the corrugated bulkhead and conventional bulkhead. Results showed that corrugated bulkhead is more effective from generated stress and weight aspects. The results show the lowest stress and deformation occurred in corrugated bulkhead are 76.6 N/mm2 with the angle from bulkhead plate 45° and 2.48 mm respectively (Chakrabarti, 1987).

2.3 Response Amplitude Operator (RAO)

Response Amplitude Operator (RAO) is a character of structure in regular waves. RAO is a function of the amplitude of structure motion respected to wave amplitude (Weibull, 1961). RAO formula can be written in equation (7).

$$RAO_M = \frac{M}{Z_a} \qquad (7)$$

Where,
RAOM = bending moment response amplitude operator (Nm/m),
M = bending moment (Nm),
Za = wave amplitude.

2.4 Response Spectrum

Structure response in the irregular wave can be obtained by transforming the wave spectrum into response spectrum. A response spectrum is defined as a spectrum of energy density in structure generated by waves. This spectrum can be generated by calculation of quadratic RAO and encounter wave spectrum (Bhattacharyya, 1978).

$$S_{(R)} = RAO^2 \times S_{(\omega_e)} \quad (8)$$

Where,
S(R) = response spectrum,
RAO = response amplitude operator,
S(ωe) = wave spectrum in encounter frequency form.

2.5 Spectral Moment

Further analysis can be statistically done by spectral moment to determine characteristics of structure motion due to wave motion. The spectral moment is used in seakeeping of structure (ABS, 2016). Spectral moment formula can be done by equation (9).

$$m_{(n)} = \int_0^\infty \omega_e{}^n S_{(R)} d\omega \quad (9)$$

Where,
mn = spectral moment nth order,
S(R) = response spectrum,
ωe = encounter frequency (rad/s).

2.6 Fatigue Life

Fatigue analysis with a spectral method modified Palgrem-Miner rule into a mathematical model. This mathematical model is applied to each sea-state (ABS, 2016). Damage formula will be translated into equation (10).

$$D = \frac{T}{A}(2\sqrt{2})^m \Gamma(\frac{m}{2}+1)\Sigma_1^M \lambda(m,\varepsilon_i) f_{0i} p_{0i} (\sigma_i)^m \quad (10)$$

Where,
D = damage,
T = design life,
m = inverse slope,
Γ = gamma function,
λ(m,εi) = Monte Carlo correction,
f0i = event frequency for each sea state,
p0i = event probability of sea state,
σi = standard deviation of stress process.

S-N diagram is obtained by test to several materials which are fluctuated regular sinusoidal load applied. These process commonly stated by coupon testing (Septiana, et.al, 2012).

$$S^m N = A \quad (11)$$

Where,
S = stress range (MPa),
m = inverse slope,
N = endurance,
A = fatigue strength coefficient.

Fatigue life calculation can be mathematically approached with design life and damage factor (ABS, 2016). The formula is showed in equation (12).

$$FL = \frac{T}{D} \quad (12)$$

Where,
FL = fatigue life,
T = design life,
D = damage.

Fatigue life calculation with a combination of load cases can be done by factor αs or service life of ship in water in the amount of 0.85 (ABS, 2016).

$$L_c = \frac{1}{\alpha_s[\frac{1}{L_1}+\frac{1}{L_2}+...+\frac{1}{L_n}]} \quad (13)$$

Where,
Lc = combination fatigue life,
Ln = fatigue life per load cases.

3 Methodology

The methodology of this research based on the theory on ABS rules and guidance of spectral fatigue analysis. As mentioned before, started by data and literature review are needed to be done first. From theories and data collected, hull modeling is performed to determine bending moment RAO as mentioned in equation (7) that will be used to generate transfer function as mentioned in equation (4) to equation (6). This performance is needed finite element analysis. Moreover, probability table and wave spectrum are modeled with a JONSWAP wave spectrum according to equation (8).

Furthermore, response spectrum is generated for each sea-state as mentioned in equation (8). These responses are analyzed statistically with spectral moment based on equation (9). Damage calculation performed with a combination of the spectral moment, correction and S-N diagram started from equation (9) to equation (12). The final step of this research is to determine the fatigue life of a combination of all load cases based on equation (12) to equation (13).

4 Result and discussion

4.1 Section Modulus and Weight Distribution

Section modulus can be calculated by analyzing part to the part based on baseline or deck and centerline vertically and horizontally. Outputs of this calculation are INA, z1 ICL, and y1. The section modulus calculation can be seen in Table 1.

Table 1. Section Modulus of Ship

Item	Value	Unit
I_{NA}	142196979,6	cm^4
I_{CL}	1460805765	cm^4
z_1	170,5	cm
y_1	0	cm

Weight distribution for full cargo and empty cargo load cases are obtained from stability document. The result shows in Table 2.

Table 2: Weight Distribution

Data	Unit	Load Case	
		Full	Empty (Ballasted)
Weight Distribution			
LWT	ton	712,1	712,1
DWT	ton	811	638
Total	ton	1523,1	1350,1
Buoyancy & Mass Center			
T	m	2,351	2,118
VCB	m	1,25	1,13
LCB	m	25,71	25,93
VCG	m	4,19	3,15
LCG	m	25,75	25,96
Displ. & Vol. Displ			
Δ	ton	1523,1	1350,1
Vol. D	m^3	1485,951	1317,171

4.2 Hull Modelling

S-N Diagram selection is based on the high value of SCF (Stress Concentration Factor) for safety reason. The result showed in Table 3. The remote area is based on midship (Fr. 15) and outer bracket.

Table 3. S-N Diagram Parameter

Parameter	Value
m	3
A	$4{,}31 \times 10^{11}$

In this research, fatigue analysis takes focus on bracket connection between longitudinal and web frame. This remote area has highest SCF (1.03 times of nominal stress). Hull modelling to be carried out by using finite element software. The result shows that the bending moment has a constant value in 1,7 m size for elements. The illustration of the finite element model shows in Figure 1.

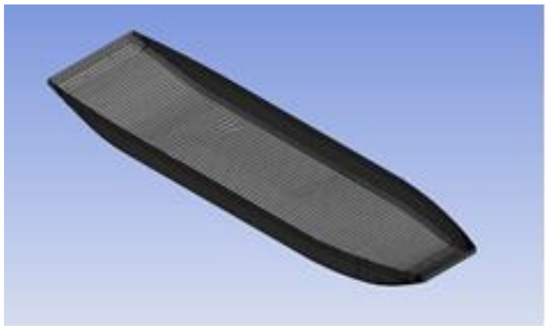

Figure 1: Ship Hull Finite Element Model

Figure 2 shows that the ship's hull is divided into panel elements. These panels are used for finite element analysis. According to Figure 2, bending moment generated from the model has no significant difference between 3rd run and 4th run respected to element size. So, the convergent element is 1,7 m.

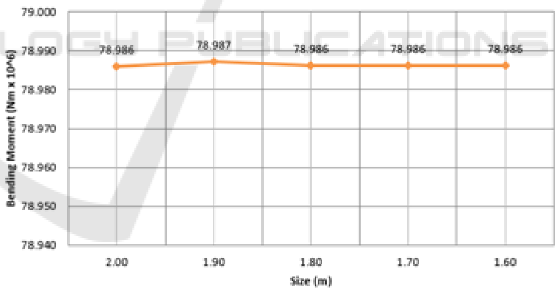

Figure 2: Element Convergence

4.3 Wave Data

Wave scatter diagram is composed of significant wave height (Hs) and zero-up crossing period (Tz). The processed data presented in Table 4.

Table 4: Bali Strait Wave Data (Yustiawan and Suastika, 2012)

Hs (m)	Tz (s)		
	5	6	7
1.0	5887	58061	14947
1.5	0	3856	8493
2.0	0	2	460
2.5	0	1	18

According to Table 4, it can be seen that at Hs = 1 m and Tz = 6 s is a dominant sea-state at Bali Strait. So, the fatigue analysis will be dominant from this sea-state.

Table 5 shows that the highest probable heading of the wave is from a southeast area with 44.244% of total recorded heading.

Table 5. Bali Strait Wave Heading Data (Yustiawan and Suastika, 2012)

Heading	$P_{heading}$	*Heading*	$P_{heading}$
E	0.003%	W	1.254%
SE	44.244%	NW	0.000%
S	25.672%	N	0.003%
SW	28.820%	NE	0.003%

4.4 Wave Spectrum

Wave spectrum is generated based on equation (3) and represented with the correlation between spectral density and wave frequency. Result for one of the spectrum with maximum spectral density is 0.75 m2s as shown in Figure 3.

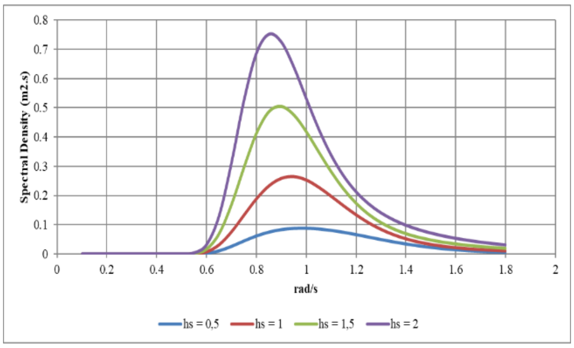

Figure 3: Wave Spectrum at Zero-up Crossing 5

According to equation (4) to equation (7), RAO stress is dominated by stress from quartering sea (135°) as shown in Figure 4 presented by red colored. It caused by a combination between vertical and horizontal stress, so the resultant of stress will happen at quartering sea.

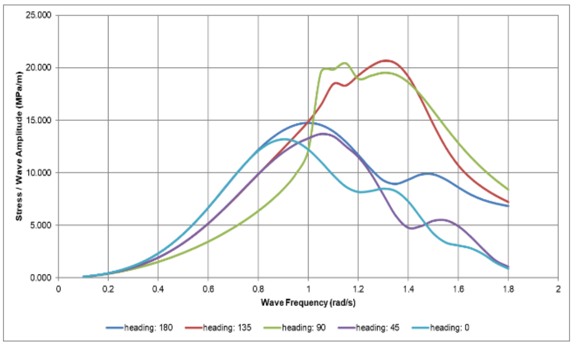

Figure 4: RAO Combination of Vertical and Horizontal Stress at Bottom Full Cargo

A generated spectral moment from structure response caused by wave shows that maximum value at Hs = 2.5 m. Table 6 is one of many spectral moments resulted.

Table 6: Spectral Moment 0th Order of Full Cargo Load Case at Bottom Bracket

Hs (m)	*Heading* 180°		
	Tz (s)		
	5	6	7
1	7,1	10,3	12,3
1.5	18,1	27,4	33,4
2	30,9	50,0	63,0
2.5	43,2	74,0	96,6

4.5 Fatigue Life

From generated result before, the damage calculation can be obtained. Damage capacity is the main factor in fatigue. Damage distribution can be analyzed by Table 7. Based on Table 7, bracket at the deck with full cargo load will have the highest value of damage so it has the shortest life of fatigue. Furthermore, the combination of load case can be coupled based on equation (13). The fatigue life calculation result shows in Table 8.

Table 7. Damage and Fatigue Life

Bracket Location	Load case	D_{actual}	Fatigue life (year)
Bottom (Rohmadhana and Kurniawati, 2016)	Full cargo	0.496	20.13
	Empty cargo	0.319	31.30
Deck	Full cargo	0.624	16.01
	Empty cargo	0.404	24.75

Table 8: Combination Fatigue Life

Bracket Location	Load case	D_{actual}	Combination fatigue life (year)
Bottom (Rohmadhana and Kurniawati, 2016)	Full cargo	0.496	28.83
	Empty cargo	0.319	
Deck	Full cargo	0.624	22.88
	Empty cargo	0.471	

Based on Table 8 it can be seen that the shortest fatigue life of the structure is on the deck with the fatigue life 22 years while at the bottom is 28 years. It is caused by the deck is the farthest distance from the neutral axis of the ship.

5 CONCLUSION

According to the analysis and results, this research can be concluded into:

1. Fatigue life of each case at the bottom is 20 years and 31 years for full cargo and empty cargo respectively where each load cases are acceptable according to ABS (20 years).
2. Fatigue life of deck structure has the shortest life approximately 16 years and 24 years for full cargo and empty cargo respectively where full cargo condition is not acceptable according to ABS (20 years).
3. Both fatigue life of combinations of load cases at the bottom and at deck are 28 years and 22 years respectively where it is acceptable according to ABS (20 years) with factor 0.85 represented as the service life of the ship.

REFERENCES

A. Yustiawan, & K. Suastika, Fatigue Life Prediction of Keel Buoy Tsunami Structure with Spectral Fatigue Analysis Method, Jurnal Teknik ITS Vol. 1 No. 1 ISSN:2337-3539, Surabaya: Institut Teknologi Sepuluh Nopember, (2012).

American Bureau of Shipping (ABS), Spectral-Based Fatigue Analysis for Vessels, Houston: American Bureau of Shipping (2016).

Ardianus, S.H. Sujiatanti, & D. Setyawan, Analisa Kekuatan Konstruksi Sekat Melintang Kapal Tanker dengan Metode Elemen Hingga. Jurnal Teknik ITS 6 (2), G183-G188, ISSN: 2337-3539, Surabaya: Institut Teknologi Sepuluh Nopember.

B. Santosa, & D. Setyawan, Lecture Handout, Ship Structure and Strength, Surabaya: Institut Teknologi Sepuluh Nopember (ITS), (2013).

D. Septiana, Soeweify, A Imron, Estimated Fatigue Life on the Tanker Ship Bracket Based on Common Structural Rules, Jurnal Teknik ITS Vol. 1 No. 1 ISSN:2337-3539, Surabaya: Institut Teknologi Sepuluh Nopember, (2012).

F. Rohmadhana, & H.A. Kurniawati., Technical and Economic Analysis of Conversion of Landing Craft Tanks (LCT) to Crossing Motorboats (KMP) Type Ro-ro for Ketapang Routes (Banyuwangi Regency) - Gilimanuk (Jembrana Regency), Jurnal Teknik ITS Vol. 5 No. 2 ISSN:2337-3539, Surabaya: Institut Teknologi Sepuluh Nopember, (2016).

M. Huda, & B. Santosa, Analysis of Estimated Age of Structure on the 10 GT Catamaran Fish Ship Using Finite Element Method, Jurnal Teknik ITS Vol. 1 No. 1 ISSN:2337-3539, Surabaya: Institut Teknologi Sepuluh Nopember, (2012).

M. N. Misbah, D. Setyawan, & W. Murti Dananjaya., Construction Strength Analysis of Landing Craft Tank Conversion To Passenger Ship Using Finite Element Method, Journal of Physics: Conference Series. 974. 012054. 10.1088/1742-6596/974/1/012054, (2018).

M. Rusdi., M. N. Misbah., T. Yulianto., Analysis of Fatigue Life on Oil Tanker Bracket with Sloshing Load, Jurnal Teknik ITS Vol. 7 No. 1 ISSN:2337-3539, Surabaya: Institut Teknologi Sepuluh Nopember, (2018).

R. Bhattacharyya, Dynamic of Marine Vehicle, U.S. Naval Academy, Annapolis: Marryland. (1978).

S. Chakrabarti, Hydrodynamic of Offshore Structures, Boston, USA: Computational Mechanics Publications Southampton (1987).

W. Weibull, Fatigue Testing and Analysis of Results, Oxford: Pergamon Press, (1961).