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24-26 October 2014 | Surabaya-Indonesia

14.40	Liveability Elements on Current Concepts of Megafloat– A Review	A. Mohd ZAMANI, A. Z.N. HANANI, Daniel M. ROSYID	MT-44

ROOM E

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Friday – October 24, 2014

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19.20	Operability Analysis of a Crane Vessel Based On Time-Domain Simulation in Lowering an Offshore Object	MURDJITO, Eko B. DJATMIKO and AriftaYAHYA	MT-19
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20.00	Numerical Study of Applied Truncation Method on Design of Deep Water Offshore Structure	ARIFIN and Abdul GHOFUR	MT-21
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20.40	Design of Blast Resistant Stiffened Plate	Raditya DANU, HANDAYANU and Yoyok S. HADIWIDODO	MT-23
21.00	Analysis on the Effects of Variation in Horizontal Distance Between FSRU and LNGC During a Side-by-Side Offloading on the Vessels Motion Behaviors and Coupling Line Tensions	Yuni A. WIBOWO, Eko B. DJATMIKO and MURDJITO	MT-24
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DAY TWO
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11.30	Triple Helical Rods with Gap as a Passive Control Device for Reducing Fluid Forces on A Cylinder	Rudi W. PRASTIANTO, Akhmad Z. Al MUSTHOFA, Erdina ARIANTI, HANDAYANU, MURDJITO, SUNTOYO and FARIDUZZAMAN	MT-27
11.50	Failure Analysis of Crane Pedestal Structure due to Blast Loading	Mochammad RAMZI, Yoyok S. HADIWIDODO and HANDAYANU	MT-28
	Chair of Session-4: **Dr. Rahimuddin**		
13.00	Mooring System Analysis of Single Point Mooring (SPM) Based on Standard Rules of Biro Klasifikasi Indonesia (BKI) : Case Study of Determination Residual Fatigue Life of Mooring Line	Muhammad IRFAN, Eko B. DJATMIKO, Daniel M. ROSYID and Budi S. PROSODJO	MT-29
13.20	Ultimate Strength Assessment of Single Hull Bulk Carrier with Bottom Damage Using Beam Finite Element Method	Muhammad Zubair MUIS ALIE, JUSWAN and WAHYUDDIN	MT-30
13.40	Fatigue-Life Assessment of InaTEWS Tsunami Buoys	Ketut SUASTIKA, SAHLAN, Wibowo H. NUGROHO, Achmad ZUBAYDI and Mohammad N. MISBAH	MT-31
	Chair of Session-5: **Prof.Dr. Achmad Zubaydi**		
14.00	Static Deformation Analysis on Corrugations Mark-III LNG Tanker by Using Finite Element Method	Rohaizad H. ROZALI and Agus PRIYANTO	MT-32

14.20	Study on the Structural Strength of Six-Leg Semi-Submersible Configured with Rectangular Hulls under Wave Excitations	Ahmad ADILAH, Eko B. DJATMIKO, Rudi W. PRASTIANTO and Wisnu WARDHANA	MT-33
14.40	A Study of the Longitudinal Hull Structural Responses on a 35,000 Ton Class Drillship due to Wave Load by the Quasi-Static Approach	Sugeng ARIYANTO, Eko B. DJATMIKO, Mas MURTEDJO and I Dewa G.A.S. YUDA	MT-34

Fatigue-Life Assessment of InaTEWS Tsunami Buoys

Ketut SUASTIKA[1], SAHLAN[2], Wibowo H. NUGROHO[2], Achmad ZUBAYDI[1], Mohammad N. MISBAH[1]

[1] Department of Naval Architecture and Shipbuilding Engineering, Faculty of Marine Technology, ITS Surabaya, Indonesia

[2] Indonesia Hydrodynamic Laboratory, Surabaya, Indonesia

E-mail: k_suastika@na.its.ac.id

Abstract

The Indonesia tsunami early warning system (InaTEWS) utilizes a number of surface buoys which are installed and operated at a number of locations in Indonesia seas, namely, off the West coast of the Sumatra island and off the South coast of the Java island. A critical structural component of the surface buoy is its keel structure, which was manufactured from a previously used ship propeller shaft. Due to the cyclic nature of the loading and the utilization of used material, a fatigue-life assessment of the keel structure is required. For that purpose, fatigue tests were performed to determine the *S-N* curve of the material. The experimentally obtained *S-N* curve has a slope*s*of approximately -1/14 or a value of m = -1/*s*of approximately 14, indicating that the fatigue strength of the material is very much lower than a typical new carbon steel,which has a value of m of 3 or 4. Furthermore, model tests were conducted to measure the wave load on the mooring line. Results of spectral fatigue calculations including the Rayleigh approximation of narrow-banded spectrum and those taking into account band-width effects, show that the fatigue life of the keel structure is approximately 15 years.

Keywords: fatigue life, tsunami buoy, InaTEWS, spectral method.

1. Introduction

The Indonesia tsunami early warning system, calledInaTEWS [1], utilizes a number of surface buoys which are installed and operated at a number of locations in Indonesia seas, namely, off the West coast of the Sumatra island and off the South coast of the Java island. The mapping of the sites of the buoy operation is drawn in Figure 1.The buoy is held at its location by using a mooring line. A prototype of InaTEWS buoy is shown in Figure 2.

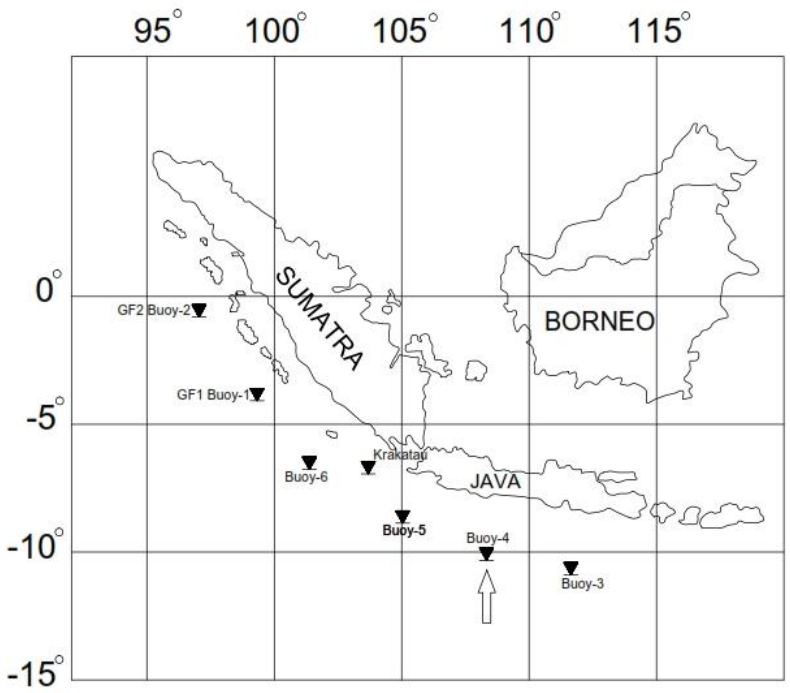

Figure 1: The mapping of the sites of operation of InaTEWS tsunami buoys [1].

Figure 2: A prototype of InaTEWS tsunami buoy [2].

Figure 3: Keel structure of the tsunami buoy [2].

The principle of the warning system is as follows. An ocean bottom unit (OBU) records the changes of the water pressure due to the seismic movement prior to the tsunami event and sends the reading to the tsunami buoy via an acoustic signal. Then, the recorded signal is transmitted to a ground station by a satellite for further analyses.

A critical structural component of the surface buoy is its keel structure (see Figure 3), which was manufactured from a previously used ship propeller shaft. Due to the cyclic nature of the loading and the utilization of used material, it is necessary to assess the fatigue life of the keel structure. It is assumed that all other structural components of the buoy have a larger fatigue life than the keel structure.

For the purpose of the fatigue life assessment of the keel structure, fatigue tests were performed to determine the *S-N* curve of the (used) material and model tests in a wave basin to measure the wave load on the mooring line.

In order to estimate the fatigue life of the keel structure, spectral fatigue calculations were carried out, including the Rayleigh approximation for narrow-banded spectrum (see e.g. [3]) and approximations taking into account corrections due to band-width effects proposed by Ortiz and Chen [4] and Lutes and Larsen [5].

2. Fatigue Tests

Fatigue tests with constant amplitude stress were conducted to obtain the relation between the stress range (*S*) and the number of cycle until failure (*N*) of the material, that is, to obtain the *S-N* curve. Ten specimens were tested with sinussoidaly varying axial stress in a room condition. To obtain the *S-N* curve, the values of the stress ranges were chosen from 50 to 80 percent of the ultimate axial stress of the material but the frequencies were kept the same (20 Hz). It is found that the endurance limit of the material (threshold stress) is approximately 250 MPa. To analyse the experimental data, the S-N curve is modeled as

$$N = KS^{-m} \tag{1}$$

where K and m are constants. Fitting the modeled *S-N* curve with the experimental data results in $m \approx 14$ and $K \approx 8.6 \times 10^{39}$. The goodness of fit between model and experimental data is given by $R^2 = 0.911$. Figure 4 shows the experimentally determined *S-N* curve together with curves of 95% confidence bounds. The value of $m \approx 14$ indicates that the fatigue strength of the material is very much lower than a typical new carbon steel which has a slope of approximately -1/3 to -1/4 or m ≈ 3 to 4 [3].

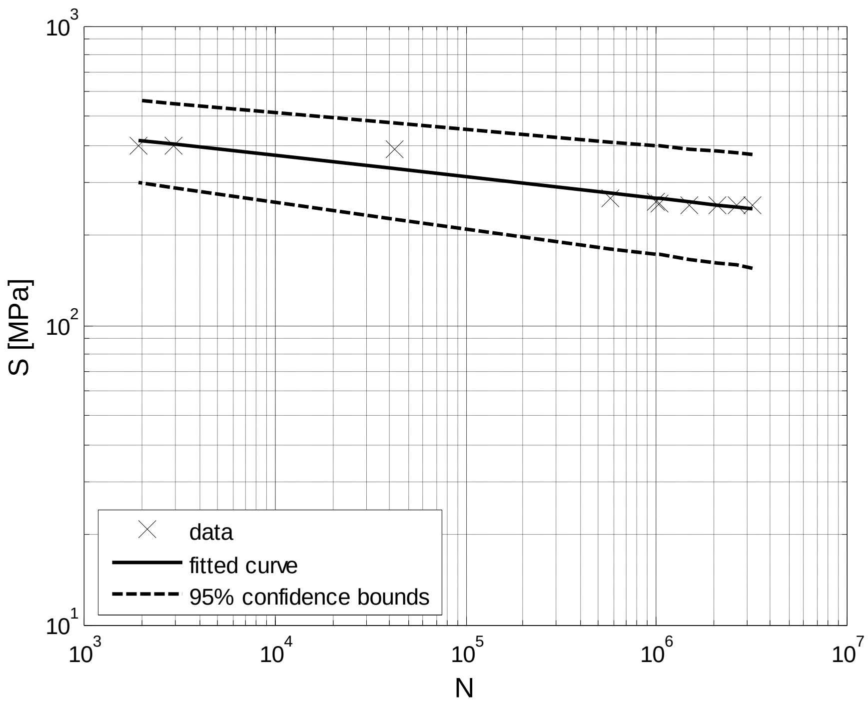

Figure 4: *S-N* curve obtained from the fatigue tests.

3. Model Tests

Model tests were conducted at the Indonesia Hydrodynamic Laboratory (IHL), Surabaya, Indonesia, to measure the buoy motions and the wave load on the mooring line [6]. A model of the buoy with a scale of 1:16 (the scale factor λ = 16) was designed and tested in a wave basin. The wave condition at the site of buoy operation is characterized with JONSWAP spectrum with significant wave height H_s = 2.0 m and peak period T_p = 6.0 s. The wave spectrum is shown in Figure5. One goal of the experiments is to obtain the stress spectrum of the keel structure, which is required for the purpose of the estimation of the fatigue life using spectral fatigue methods.

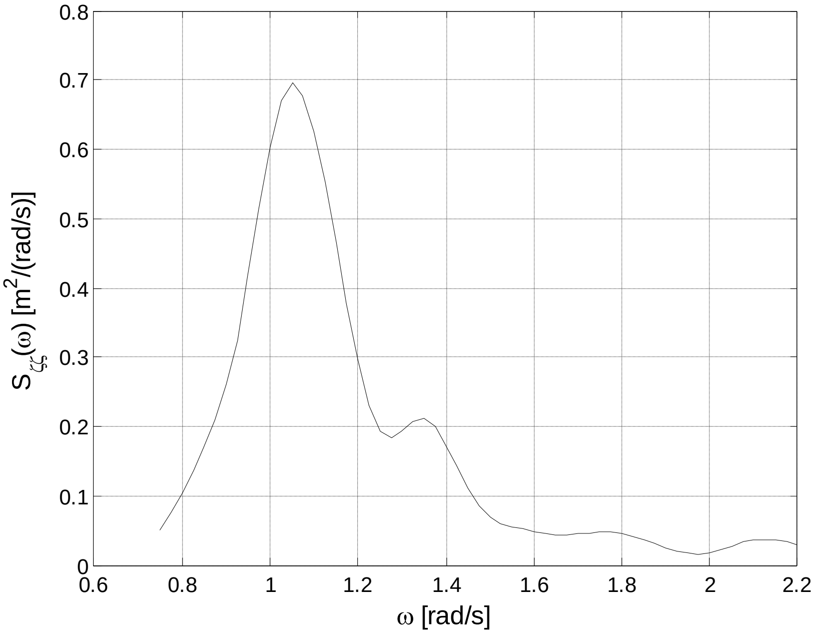

Figure 5: JONSWAP wave spectrum with H_s = 2.0 m and T_p = 6.0 s.

To obtain the keel stress spectrum, first, the response amplitude operator (RAO) of the mooring force was determined by conducting tests in irregular waves characterized with JONSWAP spectrum as stated above. To validate the irregular-wave test results, tests in regular waves with three different amplitudes and frequencies have been selected. The mooring-force RAO obtained from the experiments is shown in Figure 6.

Second, having determined the mooring-force RAO, the mooring-force spectrum can be calculated from Eq. (2):

$$S_{FF}(\omega) = \left|H_{F\varsigma}(\omega)\right|^2 S_{\varsigma\varsigma}(\omega) \tag{2}$$

where $S_{FF}(\omega)$ is the mooring-force spectrum, $H_{F\zeta}(\omega)$ is the mooring-force RAO and $S_{\zeta\zeta}(\omega)$ is the wave spectrum. The mooring-force spectrum,calculated from Eq. (2),is shown in Figure 7.

Finally, the keel-stress spectrum can be determined from the mooring-force spectrum, using Eq. (3) as follows:

$$S_{\sigma\sigma}(\omega) = |H_{\sigma F}|^2 S_{FF}(\omega) \tag{3}$$

In Eq. (3), $S_{\sigma\sigma}(\omega)$ is the keel-stress spectrum and $H_{\sigma F}$ is a transfer function defined as

$$H_{\sigma F} = \frac{SCF}{A} \tag{4}$$

where *SCF* is the stress concentration factor and *A* is the cross sectional area of the keel structure (*A* = 7250 mm^2). The transfer function $H_{\sigma F}$ is assumed to be frequency independent. As a consequence, the stress spectrum has the same form as the force spectrum. Furthermore, the stress concentration factor (*SCF*) wascalculated from a finite element method [7] and the result is *SCF* = 2.28.The keel-stress spectrum,calculated from Eq. (3),is shown in Figure 8.The keel-stress spectrum as shown in Figure 8 is used in the calculations of the fatigue life of the keel structure.

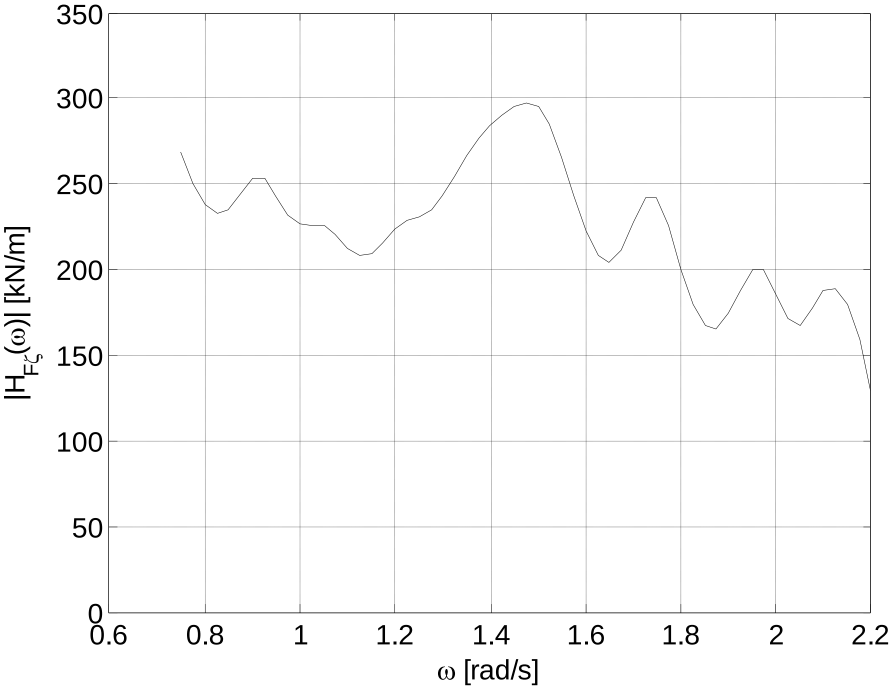

Figure 6: Mooring-force RAO.

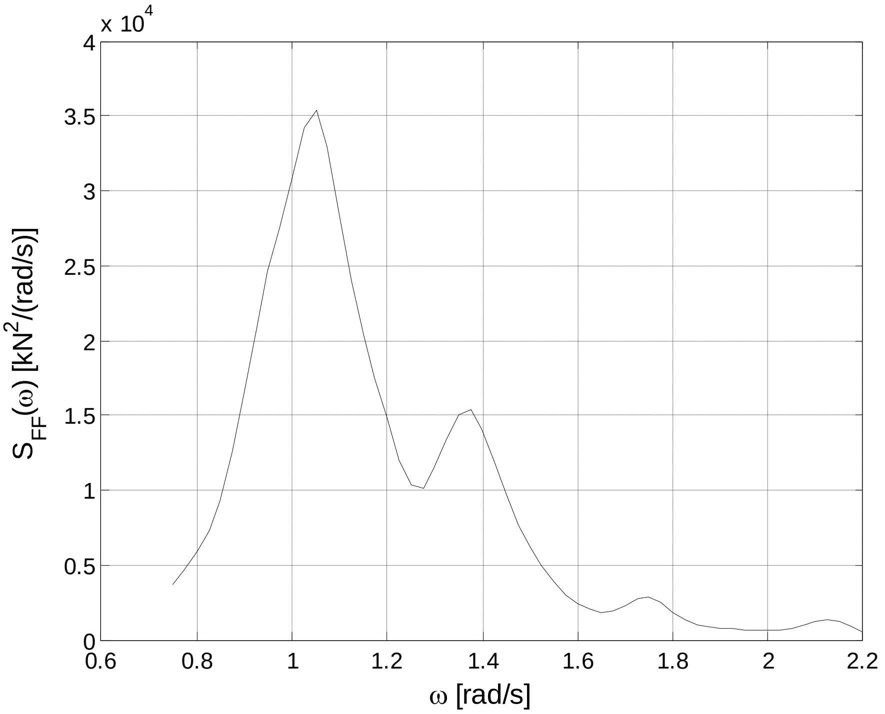

Figure 7: Mooring-force spectrum.

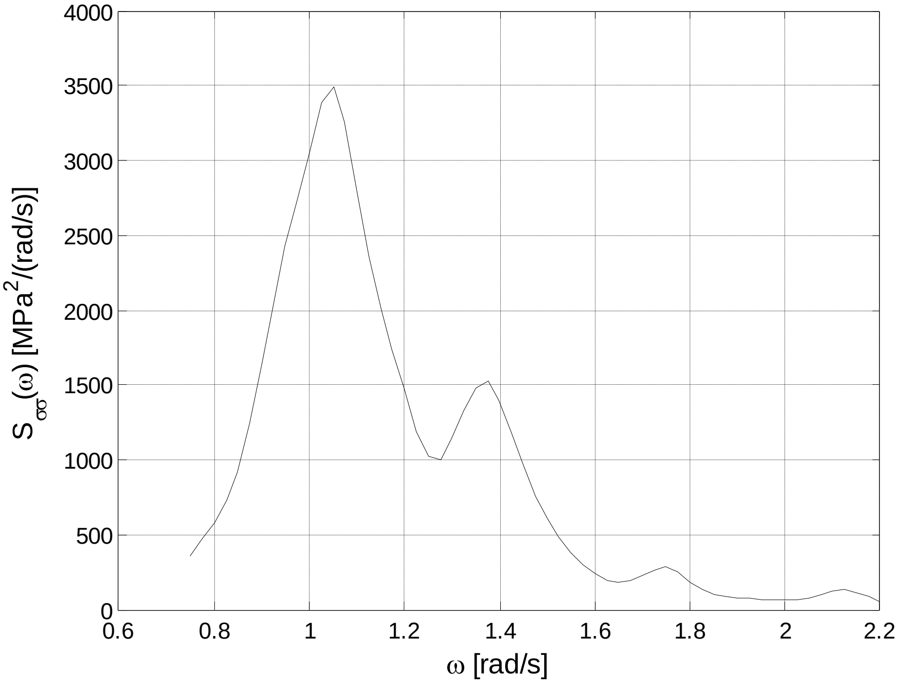

Figure 8: Keel-stress spectrum.

4. Fatigue Life Calculations

To estimate the fatigue life of the keel structure, spectral fatigue calculations have been carried out, including the Rayleigh approximation of narrow-banded spectrum and those taking into account the band-width effects. Larsen and Lutes [8] give an overview of formulas of fatigue damage rates according to the Rayleigh approximation and its modifications due to band-width effects proposed, among others, by Ortiz and Chen [4] and Lutes and Larsen [5].

The rate of accumulated fatigue damage according to the Rayleigh approximation ($\dot{D}_{RAY}$) is represented in Eq. (5) as follows:

$$\dot{D}_{RAY} = \frac{2^{3m/2}}{2\pi K}\Gamma(1+m/2)\lambda_0^{\frac{m-1}{2}}\lambda_2^{1/2} \tag{5}$$

where

$$\lambda_0 = \int_0^\infty S_{\sigma\sigma}(\omega)\,\mathrm{d}\omega \tag{6}$$

$$\lambda_2 = \int_0^\infty \omega^2 S_{\sigma\sigma}(\omega)\,\mathrm{d}\omega \tag{7}$$

The rate of fatigue damage ($\dot{D}_{OC}$) according to Ortiz and Chen [4] is represented as

$$\dot{D}_{OC} = \frac{2^{3m/2}}{2\pi K}\Gamma(1+m/2)\lambda_0^{\frac{m-1}{2}}\lambda_4^{1/2}\left(\frac{\lambda_{2/m}}{\lambda_{2+2/m}}\right)^{m/2} \tag{8}$$

whereas the rate of fatigue damage ($\dot{D}_{SM}$) according to the single moment spectral method of Lutes and Larsen [5] is represented as

$$\dot{D}_{SM} = \frac{2^{3m/2}}{2\pi K}\Gamma(1+m/2)\left(\lambda_{2/m}\right)^{m/2} \quad (9)$$

The results of the fatigue-life calculations are summarized in Table 1.It can be seen from Table 1 that the fatigue life of the keel structure is approximately 15 years.

Table 1: Fatigue life estimations according to different methods.

Method	Fatigue life [years]
Rayleigh approximation	14.77
Ortiz and Chen[4]	14.63
Lutes and Larsen [5]	15.40

5. Discussion and Conclusions

A critical structural component of the InaTEWS buoys is the keel structure, which was manufactured from a previously used ship propeller shaft (used material). It is assumed that all other structural components of the buoy have a larger fatigue life than the keel structure. To estimate the fatigue life of the keel structure fatigue- and model tests have been conducted in the laboratories.

The experimentally obtained*S-N* curve has a slope *s* of approximately -1/14 or a value of m = -1/s of approximately 14. The relatively high value of m compared to a typical carbon steel used in marine engineering (with a value of m of 3 or 4) indicates that, compared to new carbon steel, the keel material has a very much lower fatigue life.

To estimate the fatigue life of the keel structure, spectral fatigue calculations have been carried out. The spectral fatigue calculations are straight forward and generally much faster than a typical time-domain fatigue-life calculation based on a stress time series. In the first approximation the stress process can be assumed as narrow banded. In that case the Rayleigh approximation is applied, which results in a fatigue life of 14.77 years. Including the band-width correction according to Ortiz and Chen [4] results in a fatigue life of 14.63 years, which is a relatively small correction. A more significant correction to the Rayleigh approximation results from Lutes and Larsen [5], that is, their approximation results in a fatigue life of 15.40 years. From the results obtained from the three approximations presented above, it can be concluded that the fatigue life of the keel structure is approximately 15 years.

A fatigue-life estimation according to the Dirlik's method [9] has also been carried out. However, the result depends strongly on the number of stress levels used in the calculation. For that reason, the result from the Dirlik's method is not presented here. Yustiawan *et al*. [10] have also calculated the fatigue life of the same structure using the Rayleigh approximation and found a fatigue life of 7.52 years. However, there are some errors in their calculations of the spectral moments λ_0 and λ_2 of the stress spectrum and some discrepancies in the fitting parameters$K$ and m of the *S-N* curve.

The accuracy of the result of the fatigue-life estimation depends strongly on the accuracies of the *S-N* curve and of the keel stress spectrum obtained from the fatigue- and model tests, respectively. Any inaccuracy in the execution of the fatigue- and model tests will propagate to the end result, that is, to result in an inaccuracy of the fatigue-life estimation.

In the present study the fatigue tests were conducted in a room condition while the tsunami buoy operates in a corrosive environment. Taking into account corrosion effects will result in a smaller fatigue life of the keel structure. Such corrosion effects will be included in a further study.

Acknowledgments

The authors thank Baharuddin Ali, M.Eng. at Indonesia Hydrodynamic Laboratory (IHL), Surabaya, Indonesia, for the useful discussion on the interpretations of the model-test results. This research project was partly supported by the Office of Research and Public Services of ITS Surabaya (LPPM ITS), Indonesia, under grant no. 016452.28/IT 2.7/PN.01.00/2014.

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