Fatigue Life Prediction of Mooring Line on Indonesian Tsunami Early Warning Systems (Ina-TEWS) Buoy

Kusnindar Priohutomo¹, Wibowo Harso Nugroho², Erdina Arianti¹ and Dany Hendrik Priatno²

¹ Indonesian Hydrodynamics Laboratory (IHL), Surabaya, Indonesia
² Centre Technology for Maritime Industrial Engineering (PTRIM), Jakarta, Indonesia

Abstract. Ina-Buoy Gen 3.1 is one of the application of the program that has been developed by BPPT (Agency for the Assessment and Application of Technology) in order to reduce the risk of a tsunami disaster in Indonesia. This Indonesian Buoy for Tsunami Early Warning System (INATEWS - Buoy) consists of a tsunami buoy, an ocean bottom unit (OBU), a satellite and a ground station. This paper discuss about calculation of fatigue life due to wave loads for the mooring line that used to hold the buoy position in the sea. A taut mooring system is applied to the buoy until sinker at seabed. Calculation of operational tension at mooring line obtained using numerical simulation fully licensed software Orcaflex ver 11 owned by Centre Technology for Maritime Industrial Engineering (PTRIM), BPPT with wave input of $H_s=2.5\text{m}$ and $T_p=10.5\text{sec}$. The depth of sea is varied at 2088m (Sunda Strait), 3563m (Cilacap Sea) and 4082m (Bali Strait). By knowing those tension forces, stress at time history on the mooring line can be obtained. This stress time history is then applied to Palmgren – Miner formula that based on SN-Curve of the mooring line material to predict the life of the mooring line. By applying a safety factor of 2.5 it is found that the fatigue life of the mooring line at water depth of 2088m in Sunda Strait is 6.9 years, then, at water depth of 3563 m in Cilacap Sea is 15,8 years, finally at water depth of 4082 m in Bali Strait is 10 years.

1. Introduction
Indonesia as a maritime country is located at the confluence of three plates, namely the Eurasian, Indoaustralian and Pacific plates and is an area where there are many active volcanoes or ring of fires, cause Indonesia its always have potential disasters, especially earthquakes that cause tsunami. The tsunami disaster in the last 20 years (2000-2020) caused total 231,483 people number of death [1]. Start from the Aceh tsunami in 2004 and finally the tsunami that occurred in the waters of the Sunda Strait caused by the eruption of Mount Anak Krakatau.

For that Lifency or The Assesment and Application of Technology (BPPT) to design and create system for Tsunami Early Warning System (TEWS) which later will be deploy in places that are predicted to experience a tsunami event. Based on data obtained from [2] areas where tsunami frequently occur are in southern Sumatra, southern Java and in the waters of Maluku and Halmahera as shown in Figure 1.

The Tsunami Buoy has two main components in the system, part one is the Buoy (SB) which is on the surface of the water and part two is the Ocean Bottom Unit (OBU) which is on the seabed. Buoy and OBU are connected by a mooring line system that keeps the Buoy and OBU in position so
as not to affect the transmission of data from the OBU to the Buoy to be transmitted to the tsunami monitoring center at the read down station (RDS). Buoy and OBU are connected by a mooring line where the mooring line consists of type material like chain, wire jacketed and nylon rope. This tsunami buoy will be placed at a depth of more than 2000 m and spread over 14 locations in Indonesia [3] as shown in Figure 2. Therefore it is necessary to know the fatigue life of the mooring line for all material attached to the buoy and OBU, so that the calculation of the predicted fatigue life from the mooring line, it can be used as a reference for maintenance of the mooring line so that the mooring line does not get damage life d. 

Several references discuss about fatigue life of a material structure, like paper [4] where in this paper discusses the calculation of FPSO mooring line fatigue due to wave loads in the waters of Jambi Province. Model scale testing was carried out at the Maneuvering & Ocean Engineering Basin testing facility at the Indonesian Hydrodynamics Laboratory (IHL). The scale of the model used is 1:50 where in MOB the depth is set to 0.44 m. Mooring line configuration consists of total 14 lines each with spring. The wave spectrum used is Pierson-Moscow with Hs = 2.63m and Tp = 7.06 sec for 30 minutes. The results obtained from this paper are that the mooring line type chain 13 can last for 24 years, for the mooring line type chain 14 it can last for 7 years and for the mooring line type MD-Rope it can last for 24 months.

The next paper discusses the detection of structural damage life in floating structure [5] where the damage life is caused by the appearance of cracks due to metal fatigue. In this paper, the detection of damage life to metal structural components uses a numerical simulation method with a transfer
function. To observe the cracks that occur using a sensor-actuator (piezoceramics/PZT). How to detection is by observing the natural frequency of the structure due to changes in stiffness caused by cracks. The results obtained in this paper are the integration method under the frequency spectrum of the PZT sensor-actuator pair transfer function can produce more accurate early detection of damage life compared to only paying attention to the natural frequency shift of the structure due to reduced system stiffness.

The next paper that discusses fatigue material in offshore structures is [6] which in his paper discusses the assessment of fatigue life of mooring line for deep water structure. In this paper, comprehensive fatigue analysis is conducted on the mooring lines applied in a semi-submersible platform with special focus on the low frequency (LF) fatigue damage life. Several influencing factors include water surface depth, wave spectral parameters and riser system. The method used is to compare the results obtained from numerical simulation and validated using the time domain method. The results of this paper indicate that LF fatigue damage life is only calculated for a small part of the total damage life, although the LF component dominates the global motion response and tension mooring line on semi-submersible platforms. Where in the paper it is shown in case 8, the damage life that occurs is 0.02402 with a LF damage life ratio of 0.1861%, for case 1 the damage life that occurs is 0.01516 with an LF damage life ratio of 0.1857%, for case 9 the damage life that occurs is 0.008764 with an LF damage life ratio of 0.1650% and for case 10 the damage life that occurs is 0.005620 with a LF damage life ratio of 0.1542%.

Another paper that also discusses the fatigue life of mooring systems is [7] which in his paper discusses about two different types of mooring line systems for FPSO to be installed on Gulf of Mexico. One system consists of 16 mooring line (four by four) and another one consists of 12 mooring line (four by three). stiffness for mooring line is almost same. A time domain computational code is used in order to determine the extreme tension, while the spectral method is implemented for estimating the fatigue life. Environmental condition in this paper is HS=11.9 m, Tp=14.2 s, wind speed (1 hour mean)= 23 m/s and current speed (at surface)= 1.98 m/s. Results from this paper is for minimum fatigue life for chain with scheme 4x3 is 54.52 years and with scheme 4x4 is 42.24 years, and the fatigue life results for wire rope with scheme 4x3 is 502.348 years and with scheme 4x4 is 324.570 years.

Another paper discussed about mooring line its paper from [8]. In this paper its discussed about postulated failure analysis of a semi submersible in 1500 m water depth in Gulf of Mexico, installed with two other mooring namely spread catenary and taut mooring. Fatigue life damage life estimated using S-N curve approach. In this paper for environmental conditions is wind speed for 10 year=34.8 m/s and for 100 year=48.7 m/s, significant wave height for 10 year=8.2 m and for 100 year=12.2 m, peak period for 10 year=11.8 s and for 100 year=13.7 s, and current speed for 10 year=1.4 m/s and for 100 year=1.9 m/s. Results from this paper, for taut mooring minimum fatigue life at 0° wave heading in 10 year period is 1 year, at 45° wave heading in 10 year period is 1 year and at 90° wave heading in 10 year period is 2.3 year. And for catenary mooring minimum fatigue life at 0° wave heading in 10 year period is 10 year, at 45° wave heading in 10 year period is 0 year and at 90° wave heading in 10 year period is 20 year.

This paper discuss about calculation of fatigue life due to wave loads for the mooring line that used to hold the buoy position in the open sea. A taut mooring system is applied to the buoy. Calculation of operational tension of the mooring line obtained using numerical simulation software Orcaflex ver 11 with wave input of Hs=2.5m and Tp=10.5sec. The depth of sea is varied at 2088m (Sunda Strait), 3563m (Cilacap Sea) and 4082m (Bali Strait). By knowing those tension forces the stress time history on the mooring line can be obtained. This stress time history is then applied to Palmgren – Miner formula that based on SN-Curve of the mooring line material to predict the life of the mooring line. A safety factor of 2.5 is also applicable to this study.
2. Structure and Environmental Condition

For a numerical simulation, buoy is deployed on three variations of water depth at 2088 m (Sunda Strait), 3563 m (Cilacap Sea), and 4280 m (Bali Strait) with particular of buoy are listed in Table 1 and scheme for Buoy and Sinker and with OBU and Sinker as shown in Figure 3. In this paper it is only the fatigue life of mooring lines buoy calculated.

![Figure 3. Scheme Buoy and OBU for Ina-TEWS](image)

**Table 1.** Particular of buoy

| Parameter                  | Value  |
|----------------------------|--------|
| Displacement               | 1.151 ton |
| Mass moment of inertia     |        |
| x                          | 1.484 ton/m$^2$ |
| y                          | 1.484 ton/m$^2$ |
| z                          | 0.608 ton/m$^2$ |
| Centre of mass             |        |
| x                          | 0 m    |
| y                          | 0 m    |
| z                          | -1.146 m |
| Draught                    | -1.772 m |

In order to examine the fatigue life of buoy, environmental condition is used shown at Table 2.

**Table 2.** Environmental condition

| Parameter          | Value  |
|--------------------|--------|
| Direction          | 180 deg |
| Height (Hs)        | 2.5 m  |
| Period (Tp)        | 7.46 sec |
| Wave type          | Pierson-Moskowitz |
| Current speed      | 1.125 m/s |
3. Mooring Line Design

Mooring line for buoy is taut mooring with specification are listed in table 3. To reduce load from environment while the buoy is operating, on mooring line installed floater with buoyancy 25 kg per piece. Total length and composition of mooring are listed in table 4.

**Table 3. Mooring line properties**

|                | Diameter | Mass per length | Axial stiffness | Poisson ratio | Torsional stiffness | Minimum breaking load |
|----------------|----------|-----------------|----------------|---------------|---------------------|-----------------------|
| Wire jacketed  | 0.076 m  | 0.00036 ton/m    | 3646.1 kN      | 0.5           | 80 kNm²             | 57.16 kN              |
|                | 22 mm Nylon rope | 58.286 kN | 0.5 | 80 kNm² | 68.8 kN |
| Chain 3/4"    | 0.034 m  | 0.0072 ton/m     | 3.10E+04 kN    | 0.5           | 80 kNm²             | 302.1 kN              |
|                | 29 m     | 0.005 ton/m      | 2.15E+04 kN    | 0.5           | 80 kNm²             | 211.1 kN              |

**Table 4. Length and composition of mooring line**

| Line length    | Sunda Strait | Cilacap Sea | Bali Strait |
|----------------|--------------|-------------|-------------|
| Chain 3/4"     | 2 m          | 2 m         | 2 m         |
| Wire jacketed  | 500 m        | 500 m       | 500 m       |
| Nylon rope     | 600 m        | 1200 m      | 1200 m      |
| Chain 5/8"     | 6 m (floater 20 balls) | 2 m (floater 16 balls) | 5 m (floater 24 balls) |
| Nylon rope     | 600 m        | 900 m       | 1200 m      |
| Chain 5/8"     | 4 m (floater 16 balls) | 2 m (floater 16 balls) | 5 m (floater 24 balls) |
| Nylon rope     | 150 m        | 500 m       | 900         |
| Chain 5/8"     | 6 (floater 10 balls) | 4 (floater 8 balls) | 5 (floater 12 balls) |
| Nylon rope     | 113          | 120         | 75          |
| Total length   | 1981 m       | 3230 m      | 3892 m      |
4. Load Condition

All parameters that have been set from structure buoy, environment and mooring line design are entered as input in the Orcaflex numerical simulation software. Orcaflex is software that is widely used in numerical simulations in marine engineering, especially in the mooring line analysis system. Time domain analysis is used to analyze the mooring system. All environmental loads are assumed to act from head sea.

Figs 4-6 show the time series for effective tension for all type of mooring line at water depth 2088 m (Sunda Strait), 3563 m (Cilacap Sea) and 4280 m (Bali Strait). The X-axis is time simulation (second) and Y-axis is effective tension mooring line (kN). These results are summarized in Table 5, where in this table include the maximum data of tension at water depth of 2088 m (Sunda Strait), 3563 m (Cilacap Sea) and 4280 m (Bali Strait).

Figure 4. Effective tension at water depth 2088 (Sunda) for chain 3/4" (a), wire jacketed (b), nylon rope (c) and chain 5/8" (d)
Figure 5. Effective tension at water depth 3563 (Cilacap) for chain 3/4" (a), wire jacketed (b), nylon rope (c) and chain 5/8" (d)

Figure 6. Effective tension at water depth 4280 (Bali Strait) for chain 3/4" (a), wire jacketed (b), nylon rope (c) and chain 5/8" (d)
Table 5. Maximum tension mooring line

|                | Sunda Strait | Cilacap Sea | Bali Strait |
|----------------|--------------|-------------|-------------|
| Chain 3/4"     | 15.99 kN     | 14.32 kN    | 16.62 kN    |
| Wire jacketed   | 11.48 kN     | 14.31 kN    | 9.74 kN     |
| Nylon rope      | 10.10 kN     | 8.46 kN     | 9.97 kN     |
| Chain 5/8"     | 12.92 kN     | 8.29 kN     | 9.74 kN     |

5. Fatigue Life
To calculate the fatigue life of the mooring line buoy at this paper uses the S-N Curve graphic shown in Fig 7. Where in the S-N curve graphic, coefficients of S-N curves are listed in table 6, which taken from [9] dan [10].

![S-N curves polyester rope fatigue data](image)

Figure 7. S-N curves polyester rope fatigue data

Table 6. S-N curve parameter

|                | a_D         | M  |
|----------------|-------------|----|
| Stud chain     | 1.2x10^11   | 3  |
| Stud-less chain (Hs) | 6.0x10^10 | 3  |
| Six strand wire rope | 3.4x10^14 | 4  |
| Spiral strand wire rope | 1.7x.10^17 | 4.8 |

Simple criterion for calculated the extend of fatigue life induced by a particular block of constant amplitude cyclic stress, in a loading sequence consisting of various blocks of different stress amplitudes, is provided by Palmgren-Miner rules [11]. Firstly, dynamic stress is calculated by dividing the dynamic tension with breaking load to get ratio between tension divided by minimum breaking load.

From stress response spectrum, the equivalent stress and mean zero crossing periods can be determined by:
\[ \sigma_{eq} = (8m_0)^{\frac{1}{2}} \left[ r \left( \frac{2+m}{2} \right)^{\frac{1}{2}} \right]^{\frac{1}{2}} \]  

(1)

\[ T_{zo} = 2\pi m_0 \sqrt{\frac{m_0}{m_2}} \]  

(2)

\[ m_i = \int_0^\infty w^i S_i(w)dw \]  

(3)

Annual repeat number can be calculated by

\[ n_{ot} = \frac{365 \times 24 \times 60 \times 60}{T_{ot}} \times \frac{N(T_i)}{\sum_i N(T_i)} \]  

(4)

Applying Miner's rule,

\[ D_V = \sum_i D_i \]  

(5)

Finally the fatigue life is estimated by Eq. 4

\[ L = \frac{1}{D_V} \]  

(6)

6. Resulting Fatigue Life

The calculation results of the fatigue life mooring line buoy at a depth of 2088 m (Sunda Strait), 3563 m (Cilacap Sea) and 4280 m (Bali Strait) are shown in Figures 8a, 8b and 8c. In that picture, can be seen that the fatigue life for the mooring line chain 3/4" type is more than 4000 years, the fatigue life for the mooring line wire jacketed type is more than 6.9 years, the fatigue life for the mooring line nylon rope type nylon rope is more than 19.9 years and the fatigue life for the mooring line type chain 5/8" more than 500 years. The difference value for fatigue life is caused other than load from enviroment to mooring line, also influenced by minimum breaking load (MBL) from each mooring line type. The higher minimum breaking load (MBL) is for mooring line type chain 3/4" with 302 kN, and then mooring line type chain 5/8" with 211 kN, mooring line type nylon rope with 68 kN and last for mooring ine type wire jacketed with 57 kN. All fatigue life mooring line buoy its has been calculated with safety factor 2.5. These results are summarized in table 7.
Figure 8. Fatigue life of mooring line at Sunda Strait (a), at Cilacap Sea (b) and at Bali Strait (c).

### Table 7. Fatigue life summary with safety factor 2.5

|                  | Sunda Strait | Cilacap Sea | Bali Strait |
|------------------|--------------|-------------|-------------|
| Chain 3/4"       | 4256,5 years | 9262,3 years | 4972,7 years |
| Wire jacketed    | 6,9 years    | 15,8 years  | 10,0 years  |
| Nylon rope       | 19,9 years   | 40,9 years  | 20,1 years  |
| Chain 5/8"       | 588,8 years  | 822,0 years | 522,1 years |

7. Conclusions

The results of the calculation for fatigue life mooring line with safety factor 2.5 as shown in Table 7. This table presents at water depth of 2088m in Sunda strait for type chain 3/4" has the minimum life of 4256.5 years, for type wire jacketed has the minimum life of 6.9 years, for type nylon rope has a minimum life of 19.9 years and for type chain 5/8" has a minimum life of 588.8 years. Then, at water depth of 3563m in Cilacap sea for type chain 3/4" has the minimum life of 9262.3 years, for type wire jacketed has the minimum life of 15.8 years, for type nylon rope has a minimum life of 40.9 years and for type chain 5/8" has a minimum life of 822 years. Finally, at water depth of 4280m in Bali strait for type chain 3/4" has the minimum life of 4972.7 years, for type wire jacketed has the minimum life of 10.0 years, for type nylon rope has a minimum life of 20.1 years and for type chain 5/8" has a minimum life of 522.1 years. These prediction results can be used by the buoy repair team to replace the mooring line components before their fatigue life end.

8. References

[1] P. G. B. dan T. K. B. Geofisika, “Katalog Tsunami Indonesia Tahun 416-2018,” Jakarta, 2019.
[2] K. Priohutomo and W. H. Nugroho, “Strength Analysis and Assessment of Ina-TEWS Wave Glider,” *Int. J. Nat. Sci. Eng.*, vol. 4, no. 3, pp. 140–151, 2020.
[3] K. Suastika, S. Sahlan, W. H. Nugroho, and A. Zubaydi, “Fatigue-Life Assessment of InaTEWS Tsunami Buoys Fatigue-Life Assessment,” *9 th Int. Conf. Mar. Technol.*, no. October, 2014.
[4] W. Harso and Samudro, “On The Fatigue Analysis Of Mooring Lines In Irregular Wave,” *Martec*, pp. 1–14, 2004.
[5] W. Harso and Sahlan, “Metoda Pendeteksian Dini Kerusakan Struktur Kapal/Bangunan
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