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# Fatigue Life Analysis of Mooring Cleats on The N219A Aircraft Float Based on Numerical Simulation

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## Abstract

One of the procedures for rescuing a seaplane after an operational is to secure it, namely by mooring at an available port or mooring at a mooring buoy. This mooring buoy is considered a vehicle necessary for securing seaplanes in coastal conditions where it is not yet possible to build infrastructure in the form of an amphiport. To overcome this problem, seaplanes need to add a mooring cleat at the end of the bow of each float, which attaches the rope to the mooring buoy itself. So, it is necessary to study the strength of the mooring cleat itself when withstanding environmental loads. This study was carried out by modelling the mooring cleat using the finite element method to determine where the most significant stresses occur in the mooring cleat structure. Mooring cleats are modelled on deck thickness with varying thicknesses of 20mm and 40mm. The stress that occurred in the mooring cleat structure is then calculated using the Palmgren-Miner rule to determine the fatigue life of the mooring cleat for each variation. It was found that the largest von Misses stress experienced by the structure using 7075-T6 aluminium material was 147.87 MPa, which occurred in the mooring cleat, which was located on the 20mm deck thickness variation at the portside. Meanwhile, this variation's most extended fatigue life calculation occurred for the 40mm deck thickness variation on the portside with 514.43 years.

**Keywords:** Mooring Cleats, N219A, Stress, Palmgren-Miner, Fatigue Life

## 1. INTRODUCTION

The development of marine tourism in various islands in Indonesia is also a strategic and important issue related to optimizing the sustainable use of natural resources in coastal areas [1]. The types of transportation modes commonly used for tourism and other purposes have limited speed capacity. Meanwhile, visiting remote islands that are difficult to access is impossible if only ships that take a long journey are available. One of the fast modes of transportation currently being developed is amphibious aircraft. Amphibious aircraft are considered a solution for connecting island areas effectively and efficiently [2], not only in the scope of marine tourism but also in other contexts. The amphibious aircraft currently being developed by Indonesia is a development of the N219 aircraft, equipped with a pair of floats that float the aircraft to land on water.

The main supporting facility related to the development of amphibious aircraft in Indonesia is the amphiport, where the construction costs of the amphiport also require huge costs. Based on rules [3], post-operational amphibious aircraft can also be secured in various ways: docking, docking, beaching, and mooring at the pier or mooring buoy. Studies related to mooring the N219A seaplane on the mooring buoy have also been carried out [4]. This mooring buoy is moored with one rope to the seabed and equipped with two ropes that secure the amphibious aircraft when parked on the mooring buoy itself, as seen in Figure 1. The rope is attached to the mooring cleat at the seaplane float's front end. According to the FAA [3], mooring cleats are usually located along the seaplane float deck. So, this mooring cleat is expected to withstand tension loads from the portside and starboard line when experiencing cyclic environmental loads that occur when moored.

Calculating the fatigue life of a structure that is exposed to continuous environmental loads is very important [5] because it has a vital factor in terms of safety [6], especially for structures that are exposed to continuous environmental loads, for example, occurs in the transportation industry in the field of shipping [6], railways [7], [8] and aviation [8] need to be implemented.

Various studies on developing the N219A aircraft have been conducted extensively, starting with the previous RPJMN mandate [9]. Studies related to the float structure design of the N219A aircraft have been conducted [10], [11]. Studies related to takeoff and landing have also been widely discussed by researchers and academics [12], [13], [14], [15]. Operations and flight feasibility studies have also been widely discussed for case studies in Indonesian waters [16]. The analysis of the fatigue life of the float structure has also been widely discussed, such as in [17], including the material that will be used in the production of the float, which is planned to use Carbon Fiber Reinforced Polymer (CFRP).

However, few studies have discussed amphibious aircraft after landing and docking at a pier or mooring buoy. Therefore, this paper discusses the fatigue life calculation of the N219A aircraft mooring cleat float when moored to a mooring buoy after landing operations. The type of mooring used is catenary mooring, with the buoy having two ropes that function to moor (secure) the aircraft attached to the mooring cleat. Thus, the mooring cleat must be evaluated for its strength in withstanding cyclic loads during its operational period using the S-N approach and combined with the Palmer–Miner damage accumulation hypothesis. From the results of this study, the fatigue life calculation of this mooring cleat was obtained due to the environmental cyclic load received.

## 2. METHODS

### 2.1. The N219A Aircraft Float and Mooring Cleat

Data collection from the N219A Aircraft Float includes principal dimensions, as shown in Table 1. The N219A Aircraft Floats Principal Dimension. The dimensions of the N219A Aircraft Floats are needed to conduct a hydrodynamic analysis [10] to obtain the parameters required for further analysis, namely mooring analysis as previously conducted [4]. A mooring cleat is an additional structure in the form of a hook that serves as a tether for mooring lines when an amphibious aircraft is docked at a pier or mooring buoy. The configuration of this mooring analysis can be seen in Figure 1, with variations in the anchor line from 5 to 7 times the water depth [3]. The mooring cleat is located at the front of the deck float of the amphibious aircraft. The size of the mooring cleat being analyzed can be seen in Figure 2. Mooring Cleat of The N219A Aircraft Floats and Table 2. The Main Dimension of Mooring Cleat can be seen below.

Table 1. The N219A Aircraft Floats Principal Dimension [10]

| Item | Value | Unit |
|---|---|---|
| Length Over All (LoA) | 9.902 | m |
| Length Water Line (Lwl) | 9.457 | m |
| Length Between Perpendicular (Lpp) | 9.902 | m |
| Beam (B) | 1.308 | m |
| Depth (H) | 1.315 | m |
| Draft (T) | 0.740 | m |

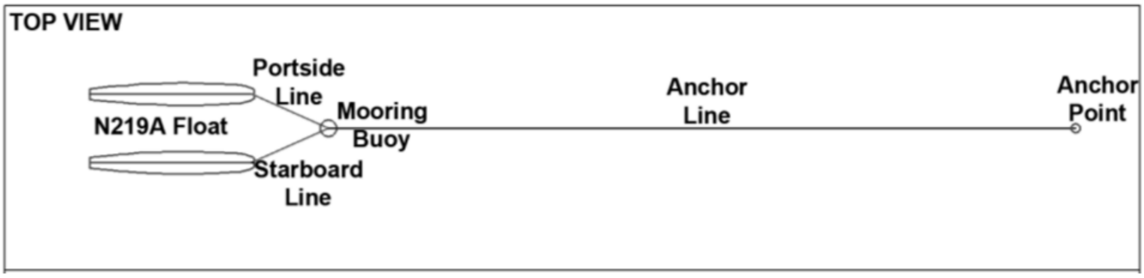

Figure 1. Configuration of The Mooring System of The N219A Aircraft Floats [4]

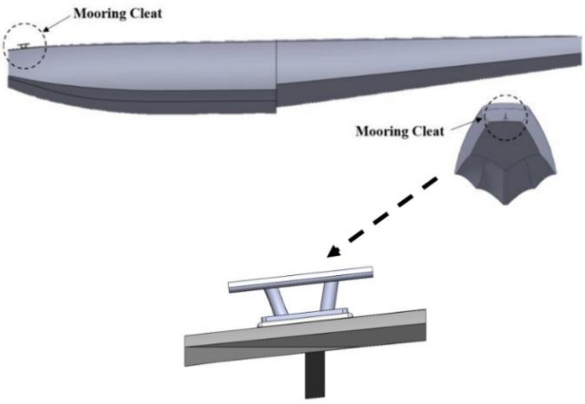

Figure 2. Mooring Cleat Detail

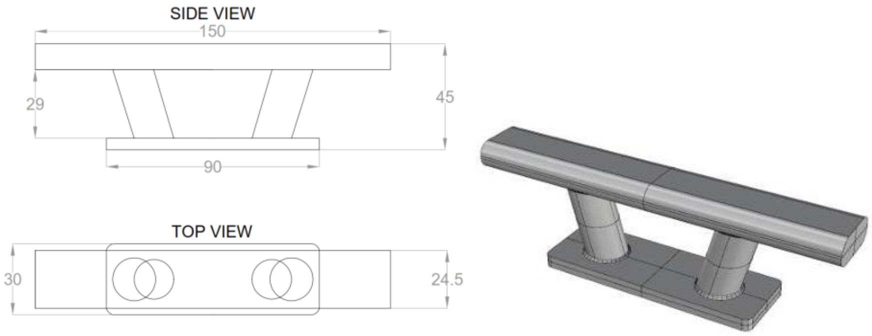

Figure 3. Mooring Cleat of The N219A Aircraft Floats [18]

Table 2. The N219A Aircraft Floats Principal Dimension [18]

| Item | Value | Unit |
|---|---|---|
| Length | 150 | mm |
| Height | 45 | mm |
| Base in Height | 30 | mm |
| Base in Width | 90 | mm |

## 2.2. Finite Element Method

This study computes the stress values that the mooring cleat structure experiences as a result of the forces operating on it using the finite element approach. The way the finite element method works is by discretizing the modeled structure into small parts so that it resembles the original shape, with the hope of making it easier to solve. This method is ultimately often used because it is considered very efficient.

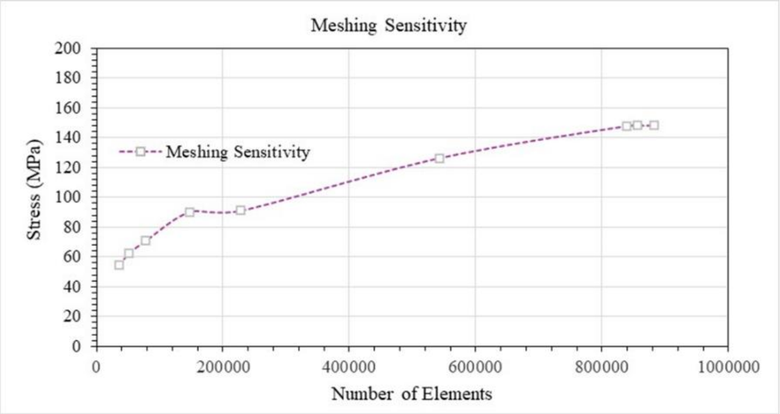

Figure 4. Meshing Sensitivity Analysis

An important aspect of Finite Element Method analysis is the meshing process. Meshing aims to discretize an object to be analyzed into small parts of a certain size. The meshing process is carried out starting from a small number of elements to a large number of elements to determine whether the obtained results have converged, which is then referred to as meshing sensitivity. Meshing sensitivity is one form of validation that will greatly affect the results of the analysis that has been conducted. Based on the meshing sensitivity analysis, the optimal mesh size can be determined for further analysis, specifically to obtain the stress values on the mooring cleat structure. In this study, a mesh size of 0.005 meters with a sizing of 0.0004 meters was obtained, with a total of 839,504 elements in the model with a thickness of 20mm and 843,335 elements in the model with a thickness of 40mm, as shown above in Figure 4.

## 2.3. Boundary Condition

The boundary condition stage in finite element analysis is one of the essential aspects because, at this stage, the structural object is not fully modelled to resemble the original structure but is modelled with imposed constraints to resemble the actual conditions. The modelled structure is a section of the float's deck thickness with variations of frame support and without frame support beneath the float's deck thickness. In this analysis, boundary conditions in the form of fixed supports must be placed on the right and left sides of the float's deck. It is assumed that the forces acting on the float are in the opposite direction to the forces from the environmental load heading in the previously conducted mooring analysis. Whereas to assume that the modelled float section is as if it is above the surface of the wavy water, the theory of the elastic foundation is adapted as a boundary condition in this study's analysis, as in the previous study [13].
In the finite element method analysis, it is modelled as a spring, which has a stiffness value. Then, to model the load acting on the mooring cleat, a force is applied to the mooring cleat structure by the direction of tension resulting from the pull of the portside line and starboard line, which are moored to the mooring buoy. Meanwhile, the force acting on the mooring cleat structure is the tension value in the mooring analysis, as shown in Figure 5 below. Meanwhile, the force values analyzed can be seen in Figure 7 below.

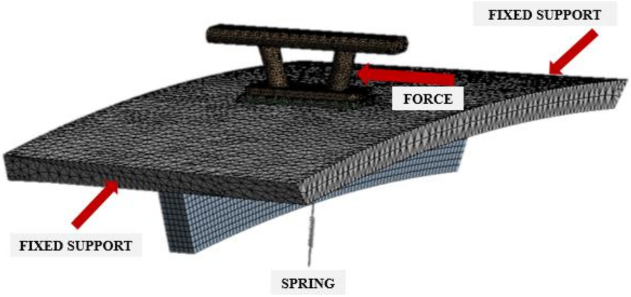

Figure 5. Boundary Condition

## 2.4. Material Properties

Mooring The analysed mooring cleats used the material properties of aluminium 7075-T6 [19], commonly used in the aviation industry, as in Table 3 below. Meanwhile, the material properties used to model the part of the float deck on which the mooring cleat rests use Carbon Fiber Reinforced Polymer (CFRP) material [20], as seen in Table 4 below.

Table 3. Material Properties of Aluminium 7075-T6 [19]

| Items | Value | Unit |
|---|---|---|
| Density | 1750 | kg/m$^3$ |
| Young Modulus | 71.700 | GPa |
| Poisson | 0.330 | - |
| Tensile Yield | 0.469 | GPa |
| Tensile Ultimate | 0.538 | GPa |

Table 4. Material Properties of CFRP [20]

| Items | Value | Unit |
|---|---|---|
| Density | 1750 | kg/m$^3$ |
| Young’s Modulus in X direction | 91.82 | GPa |
| Young’s Modulus in Y direction | 91.82 | GPa |

| | | |
|---|---|---|
| Young’s Modulus in Z direction | 9 | GPa |
| Shear Modulus in XY direction | 3.60 | GPa |
| Shear Modulus in YZ direction | 3 | GPa |
| Shear Modulus in XZ direction | 3 | GPa |
| Poison’s Ratio in XY | 0.05 | - |
| Poison’s Ratio in YZ | 0.30 | - |
| Poison’s Ratio in XZ | 0.30 | - |
| Tensile Yield | 1.315 | GPa |
| Tensile Ultimate | 1.685 | GPa |

### 2.5. Material Properties Fatigue Life Calculation

The Palmgren-Miner cumulative damage rule and an S-N curve derived from fatigue test data for a specific material are typically used to evaluate fatigue damage. For this investigation, the S-N curve of aluminium 7075-T6 is utilised. One technique for calculating a structure's fatigue life under repeated loading situations is the Palmgren–Miner rule. The Palmgren-Miner Cumulative Damage Rule was used to calculate the fatigue on the mooring cleat structure of the N219A aircraft float.

Several calculation approaches are used in fatigue life analysis, and they all have advantages and disadvantages. Still, the calculation approach analyzed uses a direct calculation method based on the time domain. However, carrying out numerical simulations requires much time [6] in this study. The N219A aircraft is assumed to only moor to the mooring buoy for 3 hours per day and is operational every day of the year. This means that the N219A aircraft lands and takes off 365 times a year, where this number does not exceed the design of the N219A aircraft's takeoff and landing of 500 times each. Figure 6 displays the S-N Curve graph for Aluminium 7075-T6. Equation 1 can be used to express the relationship between cyclic stress (S) and the number of cycles (N) if the S-N curve is known.

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

N is the cycle of the S-N Curve of the material that is sought when the stress range value is known. The values of A and m can be known from the S-N curve data in Figure 6. After applying the equation, continue calculating the stress amplitude obtained from Ansys and grouping it into stress ranges. Continue with Equation 2 below to calculate the cumulative damage D that occurs.

$$D = \sum_{i=1}^{n} \frac{n}{N_i} \tag{2}$$

Where $n_i$ is a cycle that occurs in a specific stress range, and Ni is a cycle experienced by Aluminum 7075-T6 in a specific stress range. After the cumulative damage value is obtained, the material is considered failed if the D value = 1. The next step is to determine fatigue life with Equation 3, as shown below, with D being the cumulative damage:

$$Fatigue\ Life = \frac{1}{D} \tag{3}$$

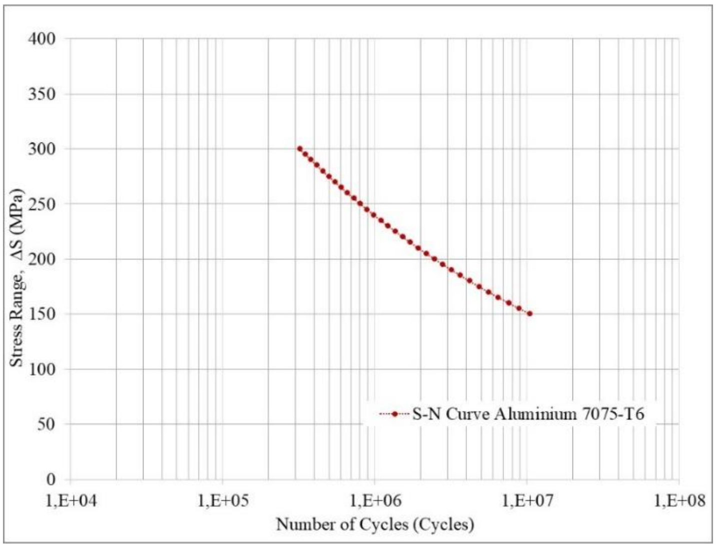

Figure 6. S-N Curve Aluminium 7075-T6 [19]

## 3. RESULTS AND DISCUSSION

### 3.1. Force

The force value was obtained from a mooring analysis simulation for 3 hours using Orcaflex software. The force obtained from the simulation is in time domain form. The simulation configuration is carried out by varying the length of the anchor line with a rope length of 5-7 times the water depth, where the water depth used in this study is 10m. From the three configuration variations, a force value was obtained that did not exceed the Main Breaking Load (MBL) value and was by the API RP 2SK criteria. So it can be concluded that the length of the mooring rope in this analysis mooring configuration does not significantly influence the mooring cleat structure; however, if viewed from the maximum offset side, the shorter the rope variation used, the smaller the anchorage area radius of this the N219A aircraft.

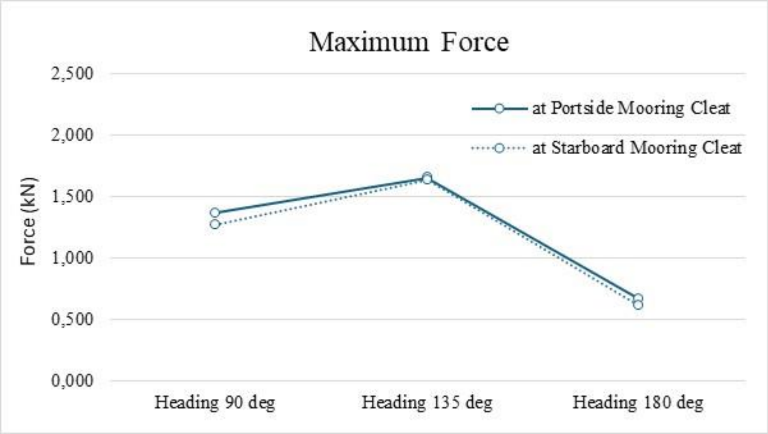

Figure 7. Maximum Force for Each Variation

### 3.2. Stress Analysis

Modelling is carried out using Ansys software to obtain the stress value that occurs in the mooring cleat structure. Define the material properties of Aluminum 7075-T6 that will be analyzed for the mooring cleat structure and define the material properties of CFRP for the part of the analyzed float. Provide boundary conditions so that the part to be analyzed represents full-scale conditions. Then, input the force value in time history form, as seen in Figure 7, to find the equivalent stress value experienced by the mooring cleat structure.

From the simulation results, the stress value per unit time is obtained. The stress value has peak values, which will later be considered in classifying the stress range so that further analysis can be carried out, namely calculating the fatigue life. One type of validation important in numerical simulations is the meshing sensitivity process, where the stress value is close to the same value with a tolerance of no more than 2%. This analysis using FEM was carried out on two variations, namely, 20mm and 40mm float deck thickness with frame support. This float deck thickness refers to previous research. The results of this simulation show the maximum stress value, which can be seen in Figure 8 below.

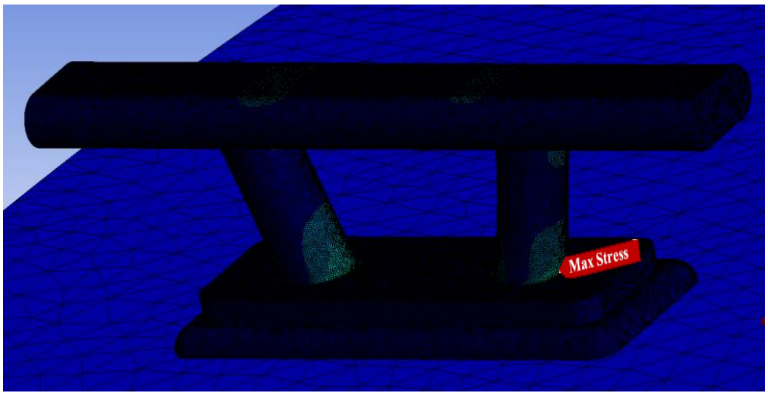

Figure 8. Stress Maximum Stress at Mooring Cleat

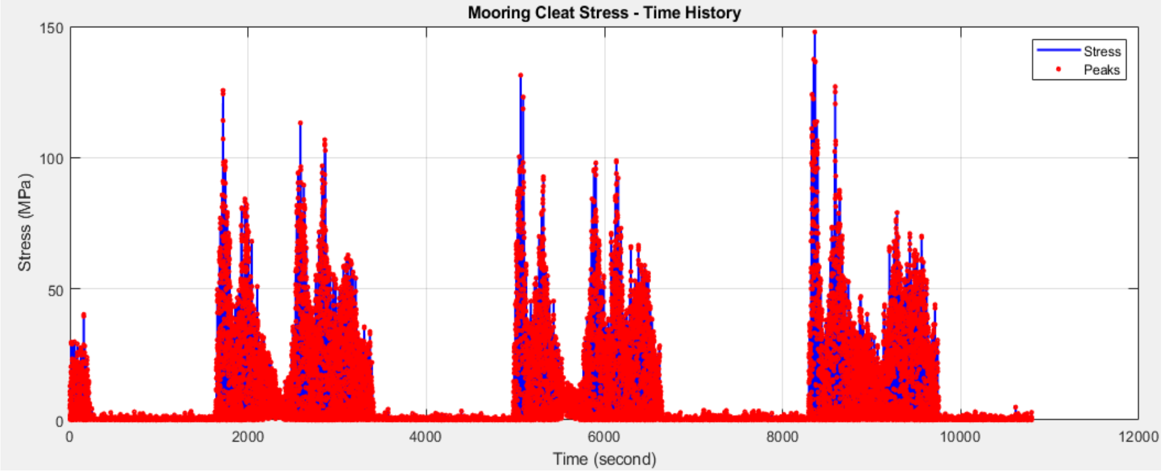

Figure 9. Time Domain Stress at Portside Mooring Cleat

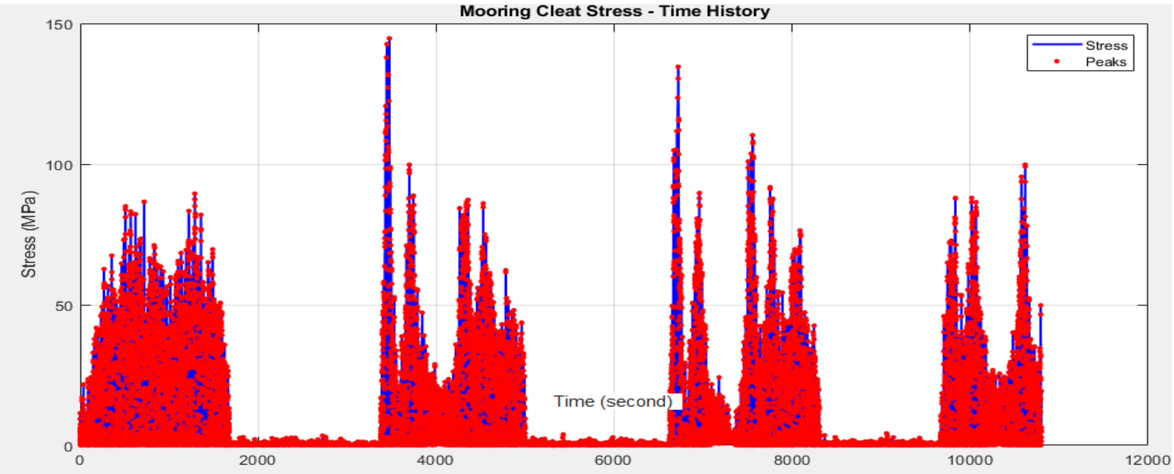

Figure 10. Time Domain Stress at Portside Mooring Starboard

### 3.3. Fatigue Life of Mooring Cleat

In addition to being used to determine the operational time calculations for seaplanes anchored at the mooring buoy, the Indonesian Aviation Agency claims that the N219A aircraft is built to land and take off 500 times each year. One amphibious aircraft, for instance, is assumed to perform one operation and be moored to the mooring buoy for three hours. This implies that the seaplane does not operate beyond the provisions because a year has 365 days and 500 appearance procedures, so it can be considered safe to observe based on the float structure's age.

After these steps are completed, divide n (cycle stress) by N (cycle material) to determine the total cumulative damage value D. The fatigue life value is then determined by dividing 1 year by the amount of cumulative damage D. The stress value obtained for 3 hours in the simulation is then calculated for the number of cycles that occur by the stress amplitude so that the n value can be known.

In comparison to the maximum stress that occurred at a deck thickness of 40mm, it was discovered that the maximum stress that occurred at a deck thickness of 20mm was higher. Conversely, the fatigue life findings will show that the longer the stress value, the shorter the fatigue life, and the greater the stress value, the shorter the fatigue life. The outcomes of the computation are displayed in Figures 11 and 12.

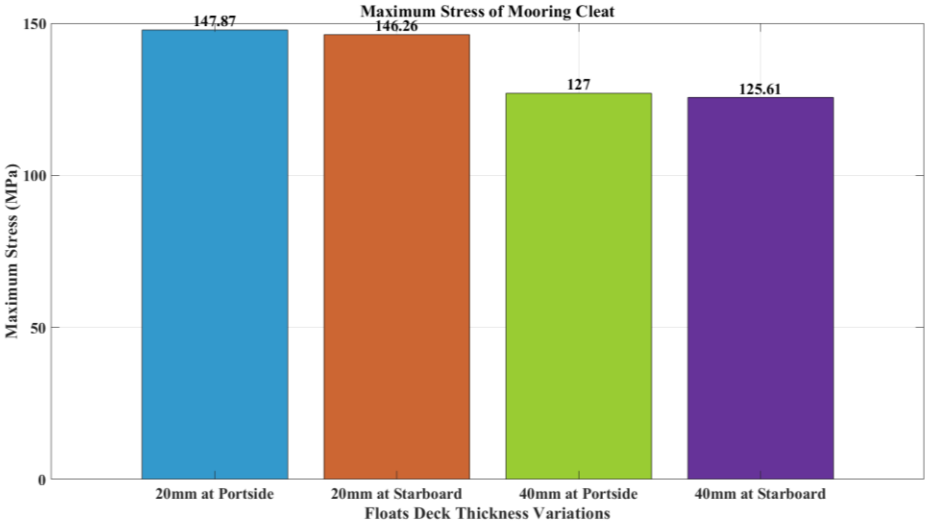

Figure 11. Maximum Stress at Portside-Starboard Mooring Cleat

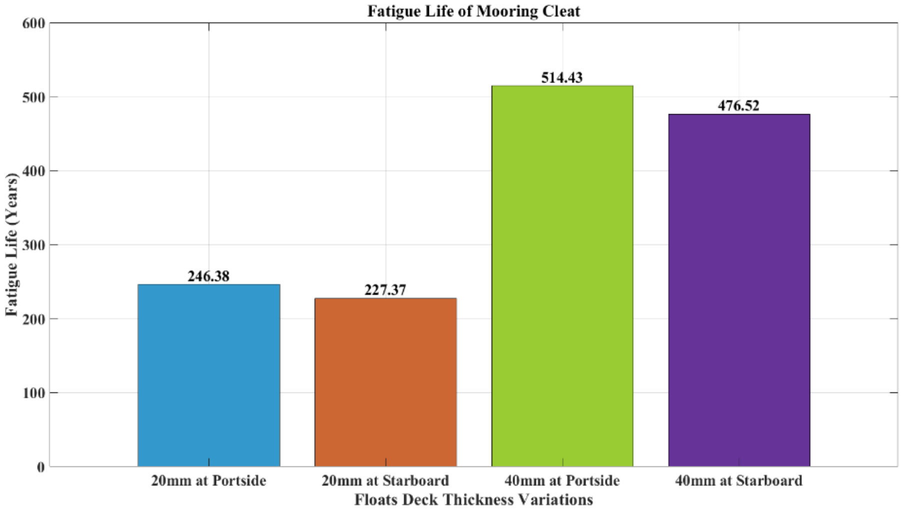

Figure 12. Fatigue Life at Portside-Starboard Mooring Cleat

## 4. CONCLUSION

Based on the above-mentioned numerical analysis results and discussion, it was determined that the von Misses stress value in the mooring cleat structure with a 20mm deck thickness was 147.87 MPa. In comparison, the maximum stress of 127.00 MPa occurred in the mooring cleat structure with a thickness of 20 mm. deck thickness 40mm. The maximum stress occurs in the mooring cleat on the port side. Likewise, stress simulations were reviewed on starboard; maximum stress of 146.26 MPa and 125.61 MPa occurred on mooring cleats with 20mm and 40mm deck thicknesses. The thicker the mooring cleat support, the smaller the stress value experienced by the structure.

All conditions mentioned above are subject to a mooring load with a nylon rope length of 5.0 meters against the mooring buoy. Meanwhile, the results of fatigue calculations based on the Palmgren-Miner Rule that occur in the mooring cleat float structure of the N219A aircraft are that the smaller the stress experienced, the longer the structure's fatigue life. By comparing the stress that occurs on the float between 20mm and 40mm shells, it was found that the fatigue life of the mooring cleat was longer when compared to 20mm, where the material properties analyzed were aluminium 7075-T6, while the float used CFRP material.

In this paper, the strength of the bolt connecting the mooring cleat and deck float is not considered, and it is assumed to be intense, so future studies need to consider this.

## ACKNOWLEDGMENTS

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