eISSN: 2721-5717; pISSN: 2747-2124 https://journal.unhas.ac.id/index.php/zonalaut

ZONA LAUT

JURNAL INOVASI SAINS DAN TEKNOLOGI KELAUTAN

FATIGUE LIFE ASSESSMENT OF DECK BARGE CONSTRUCTION USING NUMERICAL SIMULATION METHODS

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Abstract

Barges are used as the main means of transporting heavy goods such as nickel, wood, coal, and other materials placed on the main deck. Barge deck plate construction has an important role as one of the parts of the ship that supports the barge load. In a corrosive shipping environment, the deck plates will thin out over time, which has implications for the stress values and fatigue life of the construction. This study aims to analyze the local stress, deformation, and fatigue life of barge deck plate construction under different load cases using numerical simulation method with ANSYS software. The sample barge is modeled at a section of 0.2 ~ 0.7 L and subjected to pressure load on the deck. The sides of the deck are supported by fixed beams. The load cases are 50%, 75%, and 100% of full load. The results show that the maximum local stress acting on the deck plates is 190.7 MPa with a 100% load and the minimum local stress is 129.73 MPa with a 50% load. The average local stress is 160.21 MPa with a 75% load. The construction safety factor is still in the safe range. The fatigue life of the deck construction is between 10 and 21 years, with a load cycle of 170000–700000. The strength and fatigue life of the barge deck construction can be important information regarding the right amount of load, which has implications for the durability of the structure.

Keyword: *Barge; Main Deck; Stress; Fatigue Life; contruction.*

1. INTRODUCTION

In the modern era like now, it is very necessary to have a means of transportation that can support loading activities in large quantities. One of the means of transportation, namely barges, is a type of ship with a simple hull without a propulsion system. According to Puspitasari 2018, a barge or pontoon is a ship with a flat hull resembling a box that is used to transport large quantities of goods [1]**.** One of the many commonly transported by barge is Crude Palm Oil (CPO) [2]**.**
According to Adietya et al., fundamentally, barges have specific characteristics that are easy to identify, such as carrying a large load placed on the main deck; has only a manhole on the deck, has no propulsion system; has a ratio of height and width (W/H) not more than 3; the value of the shape coefficient (CB) is close to 1 [3]**.**
One of the most important parts of a barge construction is the main deck. Main decks on barges are used to accommodate large amounts of cargo, so they must be designed in such a way as to avoid excessive stresses that can cause damage [4].
Research on the structure of the barge is important to do, as an effort to detect early on the damage that may occur. Considering that barges are one of the modes of transportation that can transport large quantities of commodities. Several researchers who studied the structure of the barge deck include Alamsyah et al predicting fatigue of the barge deck structure using a numerical simulation [5]. In addition, Adietya et al., studied the maximum stress that occurs in the barge structure containing coal [3]. Riyanto et al., studied the strength of

the barge under the influence of changes in the distribution of loads on the deck [6]. Likewise with Pratama et al., predicting the value of the ship's deck strength due to dynamic loading with different ship sizes [7].
The research was carried out in an effort to ensure the technical feasibility of the ship's structure. In the course of the research developed in predicting the fatigue life of construction. Like Pangestu et al., predicting ship construction fatigue using the Simplified Fatigue Analysis method [8]. Misbah et al., studied the fatigue of ship construction using the Mean Value First Order Second Moment method [9]. The MVFOSM method and the FORM First Order Reliability Method (FORM) were used by Liu et al., in optimizing the structure with different objects [10]. Alamsyah et al., detected the fatigue life of the pontoon construction using numerical simulations based on the welded connection model, and the type of profile [11]. Determination of fatigue life can be done by conducting a stress analysis on the construction first. As with Alamsyah et al., detecting stress concentration points and fatigue life in structures using numerical simulations and the Palmgren-Miner cumulative linear damage theory [12] [13].
The cycle of structural damage that experiences fluctuating stress has implications for fatigue. The load benchmark that has the most implications in the process of structural fatigue is stress fluctuations [14]. Fatigue life is determined based on the total fatigue damage observed from the stress point which produces a cumulative fatigue damage index. The index is then used as a coefficient in determining the fatigue life of the structure [15]. The accumulated fatigue damage value (D) refers to the stress-cycle (SN) curve approach by applying the Palmgren-Miner cumulative linear damage theory [16] [17]. To predict fatigue life, we have to know the value of fatigue damage by using a simplified fatigue analysis equation referring to DNVGL-RP-0005: 2014-06 [18].
Many studies on the fatigue of a structure have been carried out, especially related to the topic of marine materials and construction as Yuan et al predicts the fatigue of marine grade materials under the influence of hydrodynamic loads [19]. Fang et al studied offshore structures using the fatigue crack growth prediction method [20]. Deng et al., investigated biaxial proportional low cycle fatigue & biaxial accumulative plasticity of gastric inclined fracture plates using numerical analysis [21]. Lee et al, evaluated the fatigue of low-cycle materials in pipe joints using the structural strain method [22]. Likewise, Dong et al studied the behavior of ratcheting failure of certain materials under the influence of cyclic loading [23]. Kim et al analyzed the fatigue of the mooring chain structure on FPSO vessels with certain operating scenarios using the non-linear finite element (NLFE) method [24]. Kong et al observed fatigue in transverse welded joints under 2G and 3G welding positions using experimental methods compared to numerical simulations [25]. G. Storhaug also examines the fatigue life of container ship structures due to the influence of whipping and springing operating scenarios which are loading under extreme conditions [26]. Prediction of structural fatigue life is studied in various methods. Likewise, this study adopted a numerical simulation method to detect the fatigue life of the main deck of the barge. The main objective of the study was to determine the maximum stress and fatigue life (estimated age) on the main deck construction when subjected to a load.

2. METHODS

The method adopted instress analysis, namely numerical simulation using ANSYS Academic Research Mechanical and CFD software [27] based on the load scenario when the barge is operating.

2.1. Main Dimensions of Barges

The main dimensions of the barge are shown in Table 1 as follows.

Table 1. The main dimensions of the barge [28]

No	Components	dimension	units
1	Length Over All (LOA)	91.44	meters
2	Breadth (B)	27.43	meters
3	Height (H)	5.50	meters
4	Dead Weight Ton (DWT)	10070	tons
5	Draught (T)	5.00	meters

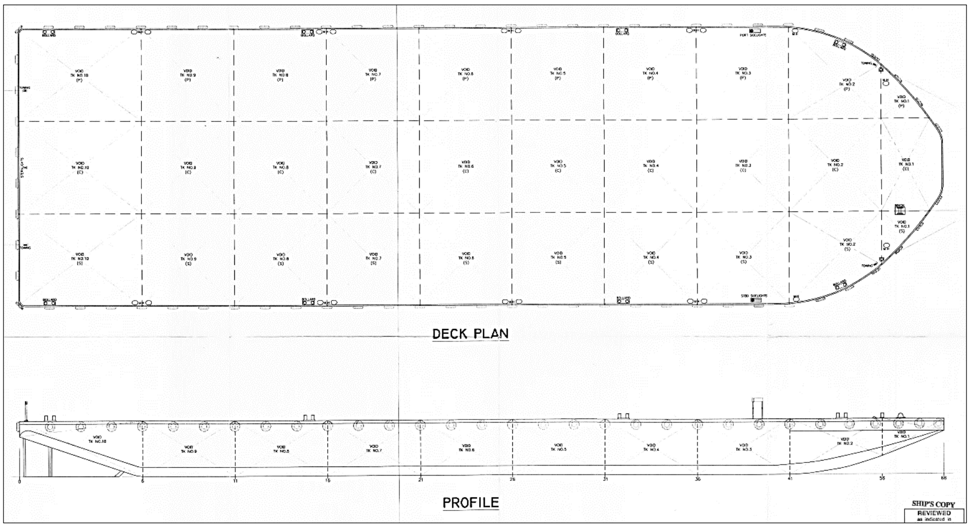

Figure 1. General Arragement [28]

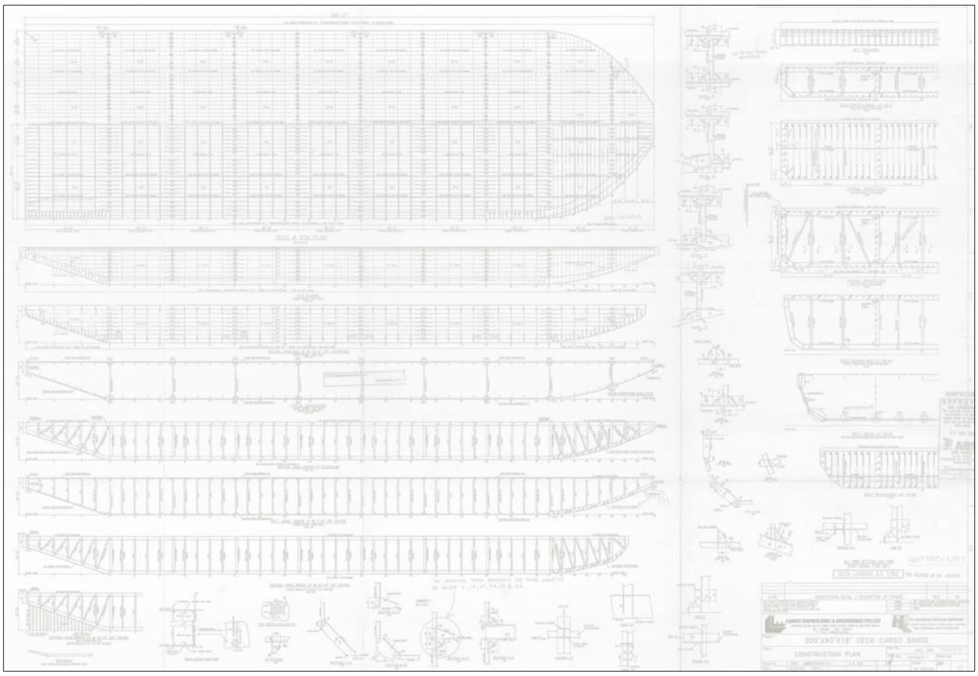

Figure 2. Midship & Profile Construction [28]

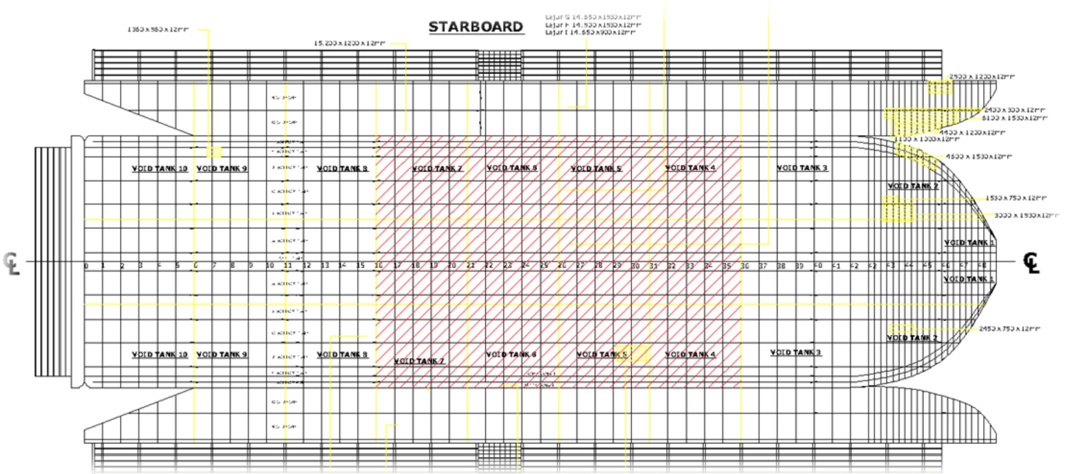

Figure 3. Shell expansion [28]

After obtaining the main vessel size data, the next process is to identify the part of the vessel to be analyzed. The analysis is carried out on the midship section, namely frames 21 to 31. After that, a general arrangement image is needed to find out in detail about the dimensions of the profile, the distance of each web frame, and the distance between the bulkheads. The thickness of the plate is taken based on the shell expansion drawing. General arrangement, construction, and shell expansion drawings are shown in Figures 1, 2 and 3.

2.2. Barge Model

In analyzing the stress required finite element software (FE) [27]. For that, a construction model is needed. The construction model made is two empty spaces in the midship of the ship, precisely on frames 21 to 31. The data needed in making the model are the width of the ship, the height of the ship, the length of the midship of the ship, the dimensions of the L profile, web frames, bulkheads, and plate thickness. The modeling of the software is shown in Figure 4 as follows.

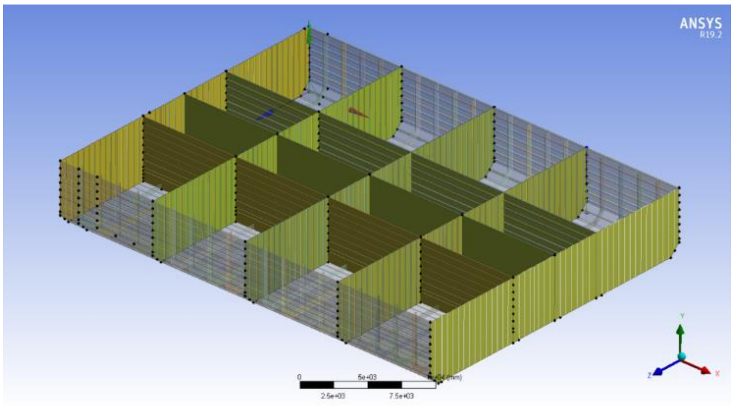

Figure 4. Barge ship 3D model

2.3. Meshing Model 3D Barge

Meshing is one of the steps carried out when the analysis uses the numerical simulation method with ANSYS. This stage divides the model into small, uniform elements. There are several main options that must be considered in determining meshing, including mesh size, mesh type, and size function. The results of the meshing model are shown in Figure 5.

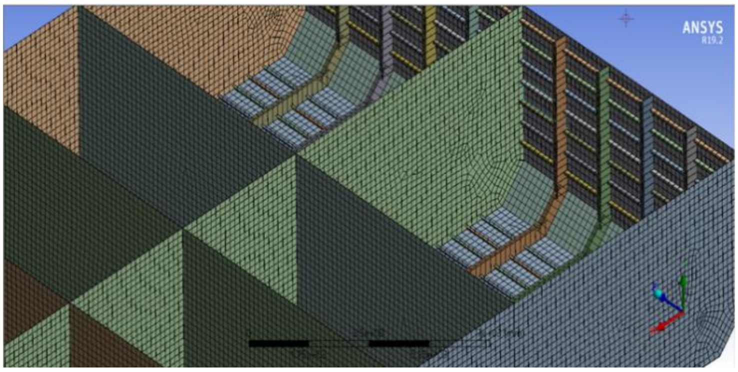

Figure 5. Meshing Model 3D Barge

2.4. Payload Scenario Calculation while operating.

The calculation of this loading is obtained from the volume of cargo in space (m^3) multiplied by the density of Indonesian coal, which is 1.35 g/cm^3 for solid bituminous coal. The weight obtained has been adjusted to the condition of the ship when it is fully loaded. The recapitulation of the calculation results for several payload scenarios is shown in Table 2 below.

Tabel 2. Load scenario

No	Loadcase Scenario	Load of Value (tons)	Load of Pressure (MPa)
1	100%	2367	0.047
2	75%	1775.4	0.034
3	50%	1183.6	0.023

The load for the model is converted to megapascals (MPa), this is because the software only accepts MPa units, where 1 MPa = 100.36113567 tons/m^2. The value of each pressure in each load scenario will be applied to the model. Because the software cannot do prismatic loading, the loading is assumed to be evenly distributed on the main deck, which is shown in Figure 6 as follows.

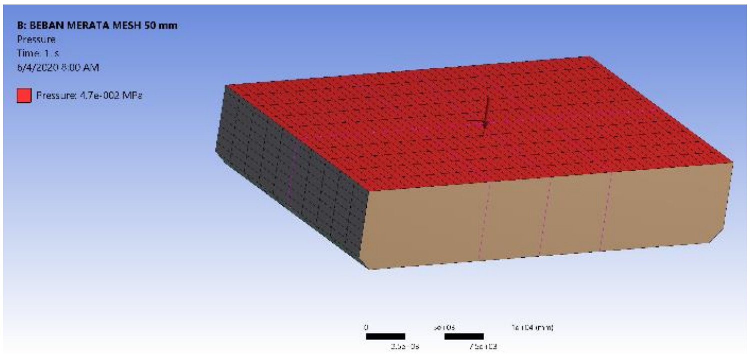

Figure 6. Load press on main deck

2.5. Fatigue Life Assesment

Calculation of fatigue life using a simplified fatigue analysis equation "Structure Fatigue Assessment" [18]. Hotspot stress is the main consideration in predicting the fatigue life of the structure. This is related to the use of Stress and Cycle (SN) diagrams. The basic parameter of fatigue loading is the stress range, where cracking depends on the number of cycles (SN diagram) [29].
The following is a series of formulas used in determining the fatigue life of a structure.

$$D = \frac{v_0 T_d}{\bar{a}} q^m r \left(1 + \frac{m}{n}\right) \leq \eta \tag{1}$$

$$v_0 = \frac{1}{4.\log_{10}(L)} \tag{2}$$

$$q = \frac{\Delta\sigma_0}{(In\, n_0)^{1/h}} \tag{3}$$

$$h_0 = 2.21 - 0.54 log_{10}(L) \tag{4}$$

$$\mathrm{h} = h_0 + \frac{h_a \times z}{T_{act}} - 0.005(T_{act} - z) \tag{5}$$

$$Fatigue\ Life = \frac{Design\ Life}{D} \times years \tag{6}$$

where D = Accumulated Fatigue Damage m = negative inverse slope of the S-N curve; q = Weibull stress range scale distribution parameter; $\boldsymbol{v_0}$ = Average zero up-crossing frequency; $\boldsymbol{n_i}$= number of stress cycle over time period; $\bar{\boldsymbol{a}}$ = intercept of the design S-N curve with the log N axis; T_d = Design life of ship in seconds (20 yrs = 6.3 x 10^8 sec); $\Gamma\left(\mathbf{1}+\frac{\boldsymbol{m}}{\boldsymbol{h}}\right)$ = Gamma function; and Design life = 20 years referred to Det Norske Veritas (DNV) rules.

3. RESULT AND DISCUSSION

From the results of the analysis using the numerical simulation method with ANSYS, hotspot stress was detected for each barge operation scenario shown in Figures 7, 8, and 9.

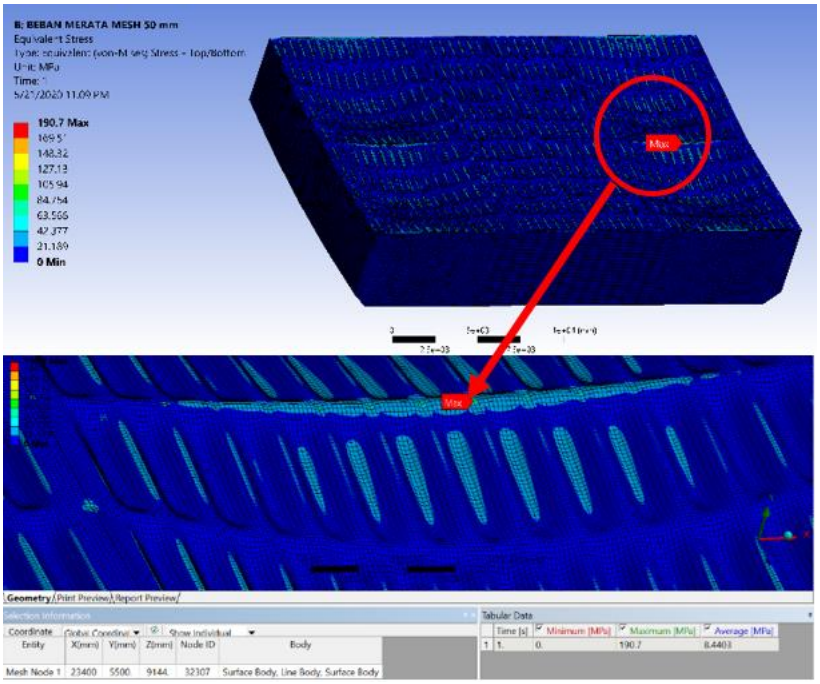

Figure 7. Operation scenario 100% payload

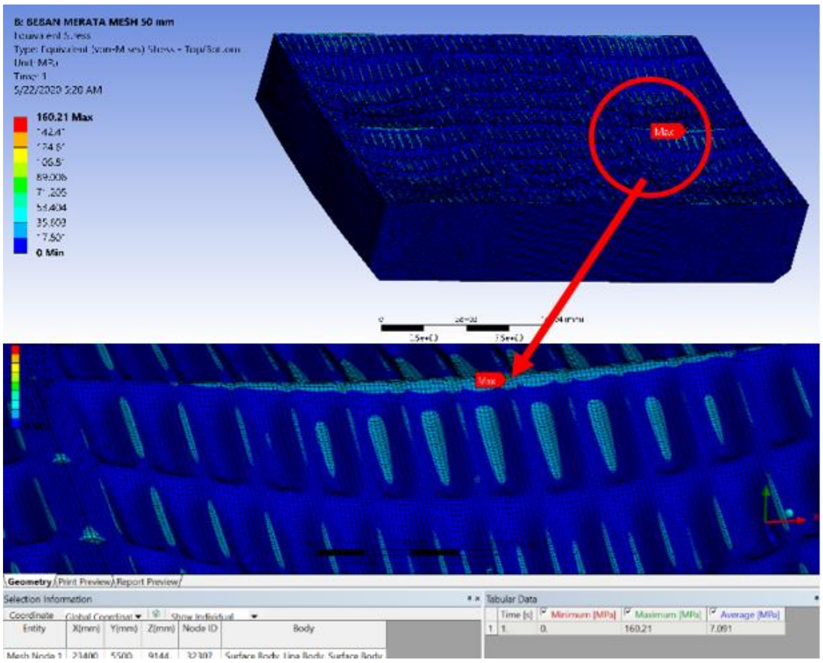

Figure 8. Operation scenario of 75% payload

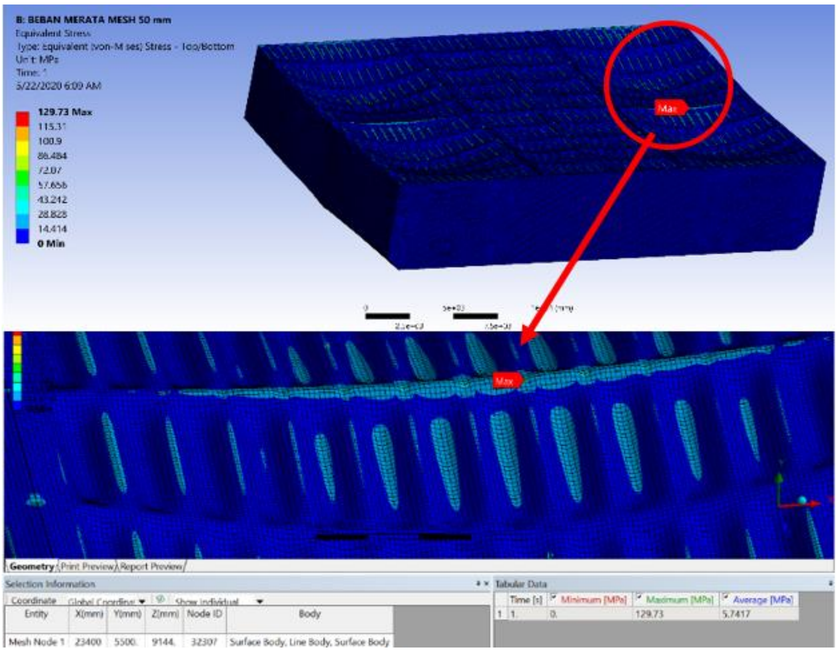

Figure 9. Operation scenario of 50% payload

Recapitulation of hotspot stress data detected in numerical simulation results which are the main parameters in determining fatigue life are shown in Table 3 as follows.

Table 3. Recapitulation of hotspots stress, fatigue damage, and fatigue life

No	Load Scenario/ Variable	100% (tons)	75% (tons)	50% (tons)
1	Stress σ_v (MPa)	190.70	160.21	129.73
2	Number of Cycle (N)	1.7×10^5	3×10^5	7×10^5
3	Fatigue damage (D)	1.88	1.48	0.95
4	Fatigue life (years)	10.66	13.49	21.16

Table 3 shows the operating scenario of a 50% load of coal having a stress value of 129.73 MPa and a fatigue life of 21.16 years. The operating scenario of 75% coal load has a stress value of 160.21 MPa and a fatigue life of 13.49 years. And the operating scenario of 100% coal load stress value is 190.70 MPa and fatigue life is 10.66 years. Table 3 provides the standard data for making the SN curve as shown in Figure 10 as follows.

4. CONCLUSIONS

The response of the barge deck structure after simulating operational loads using numerical simulation methods shows a linear increase in local stress values along with an increase in the amount of load applied. This is indicated by the finding of the maximum stress value at the joints of the deck plates and the deck cross beams. The stress point is the hotspot stress, which can be used as a reference to predict structural fatigue using the simplified method. The number of load cycles resulting from the simulation is inversely proportional to the fatigue life of the structure. These results can be validated using other methods, such as beam theory and the Smith method. In the future, research will be carried out on the same object but using other methods.

ACKNOWLEDGMENTS

Thank you to the integrated laboratory of the Kalimantan Institute of Technology for facilitating this research. Thanks also to the reviewers for their input and constructive criticism so that this article deserves to be published and read by many people.

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