The Fatigue Life Assessment of Sideboard on Deck Barge Using Finite Element Methods

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ABSTRACT

A Deck barge is a type of ship that has a flat hull used to transport large amounts of cargo such as wood, coal, sand, etc. The deck barge uses retaining walls to transport bulk loads on deck known as sideboards which can collapse due to fatigue life. The purpose of this research is to determine the maximum stress and fatigue life of the sideboard construction based on the height of the bulk load on the sideboard using coal as the bulk load. The method used in this research is the finite element method with a high load case of coal loading to the sideboard is 2.24 m, 2.60 m, and 2.96 m. The results showed that a high load case of 2.24 m detected a maximum stress value of 79.25 MPa and a fatigue life of 81.16 years with 10 x 10⁵ cycles. Load case with a high load of 2.60 m detected a maximum stress value of 110.11 MPa and a fatigue life of 24.72 years with 3.53 x 10⁵ cycle. For a high load case of 2.96 m, a maximum stress value of 146.80 MPa was detected and a fatigue life of 9.28 years with 2 x 10⁵ cycle. There is an increasing stress value by the rise of the load height against the sideboard and there is a decrease in the fatigue life in the construction.

INTRODUCTION

Puspitasari 2018 stated that a barge or pontoon is a type of ship that has a flat hull in the shape of a large box that is used to transport goods and towed by tugboats or used to accommodate the tides, such as on a floating dock [1]. The barge is also used to transport crude palm oil [2]. The deck barge transports large quantities of cargo placed on the deck as well, such as wood, coal, sand, and others. Barges do not have a propulsion system like ships in general, but there are also badges that have their own propulsion system, such as Self-Propelled Barge. This type of barge is different because it has its own propulsion and the shape of the hull is the same as the one which is usually operated in shallow waters and inland waterways [3]. The characteristics of the Deck Barge are: only transporting commodities on the deck; unmanned; without its own propulsion; does not have hatch holes in the deck except for manholes which are closed and lined with gaskets; has a ratio breadth to the height of (B/H) ≤ 3; has a block coefficient of 0.9 or more [4]. Research on the fatigue limit of the barge structure is an important concern because it is one of the...
modes of transportation of goods and bulk cargo in large quantities.

Previous research conducted by Arswendo et al. showed the maximum stress value that occurs in constructing the 1036 DWT coal deck barge under the influence of calm water [4]. Another research by Mulyatno et al. showed the maximum stress value in deck construction with other types of vessels [5]. Also, Adnyani has conducted research on deck strength on the Deck Barge 10070 DWT by simulating two load cases during operation [6]. Riyanto et al. examined the strength of the deck barge due to changes in the distribution of load on the deck in calm water conditions [7]. Pratama et al. examined the strength of the ship deck due to changes in load distributed [8]. In his research, the deck construction is loaded vertically, in the same direction as the y-axis, which is the loading from the load. The loading is defined as linear static, with fixed ordinate axes in numerical calculations [9]. All of the previous research used the finite element method. The purpose of those research is to ensure that the deck strength of the ship is still sufficient. One of the assessments carried out is to determine the strength of the construction. It is conducted by detecting the stress ratio in which it is compared to the working stress that occurs in the construction due to external loads that happened on the ship with the allowable stress of the material [10]. To fulfill the allowable stress (yield strength), the modulus of construction is increased by increasing the thickness of the plate or longitudinal carling [11]. The strength of the construction, given a continuous load, its material will reach the point of fatigue which results in permanent damage as a process of changing the permanent structure at one point becoming a crack. [12].

Material properties, geometric properties, and manufacturing processes can affect the quality of a design [13] so that the selection of the right material can affect the performance of ship construction. The fatigue fracture mechanism consists of 3 stages, namely: crack initiation, crack propagation, and final fracture [14]. The rate of crack propagation is proportional to the stress range and is usually represented by the stress intensity AK, which is a function of stress magnitude, size, fracture geometry, and structural geometry [15]. Alamsyah et al. detected the local stress and fatigue life of the pontoon lift using numerical simulations with the defines the number of cycles to failure, N(S), when a material is repeatedly cycled through a given stress range S (S-N curves approach), based on the weld joint model, and the profile section model [16]. Pangestu et al., examined the fatigue life of ship construction using the Simplified Fatigue Analysis method [17]. Alamsyah et al. detected hotspot stress and fatigue life on structures using numerical simulations and the Palmgren-Miner cumulative linear damage theory [18] [19]. Misbah et al. estimated the fatigue life of ships using the Mean Value First Order Second Moment method [20]. The same results on the use of the MVFOSM method and the FORM First Order Reliability Method (FORM) were also shown by Liu et al. in optimizing the reliability-based missile suspension structure [21]. The research was conducted not only to ensure the eligibility of the strength of the vessel structure but also to predict the fatigue life of the construction. Determining the fatigue life can be done by doing a stress analysis on the construction first.

In 2006, the International Association of Classification Societies (IACS) developed a new regulation for the construction of tankers and bulk carriers, namely Common Structural Rules (CSR) [22]. Repetitive loads that occur continuously can result in fatigue on the ship’s structure. Fatigue is a type of failure (fracture) in a component due to repeated and changing dynamic loads. It is estimated that 50%-90% of mechanical failure occurs due to fatigue [23]. Fatigue is a process of the cycle after cycle of damage accumulated in structures that are subjected to fluctuating stresses, through several stages starting from the initial crack free to the failure state. The most influential load parameter is the fluctuation of the stress component or commonly referred to as the stress range [24]. There are two types of fatigue, Low-cycle fatigue that occurs for a low number of cycles less than 5x10³ cycles, and High-cycle fatigue that occurs for a high number of cycles. Fatigue life is calculated based on the total calculation of fatigue damage from stress hotspots which produces a cumulative fatigue damage index. This index is then used as input to calculate the fatigue life of the structure based on the fatigue life equation where the design life according to CSR is 25 years [22]. To determine the value of “D” or Accumulated Fatigue Damage, the S-N curve approach by applying the Palmgren-Miner cumulative linear damage theory is used [25][26]. To predict fatigue life, we must know the value of fatigue damage by using the simplified fatigue analysis equation determined by DNVGL-RP-0005: 2014-06 [27].

This study uses finite element (FE) methods where numerical procedures can be used to find solutions to various problems in engineering [28]. The numerical analysis discusses several aspects that have particular relevance to the response of ship structures, including the importance of determining the weld model, the effect of failure criteria, material relations in complex structural simulations, and application of the scaling law in assessing the impact of full-scale structural response [29]. An accident collapsed case has occurred in constructing a sideboard of deck barge 10486 DWT while transferring coal [30]. The initial hypothesis was due to construction fatigue. The accident shows an important study regarding sideboard construction on the deck barge, including strength, fatigue life, the form of construction, and external factors such as corrosion, pressure from the load, etc. In this study, an analysis of the strength of the barge sideboard construction was carried out, and the fatigue life of the construction was estimated. The benefits of the research results are
expected to become a reference in the barge sideboard design process and as a reference to determine the construction replacement time correctly.

METHODS

The stress analysis uses numerical simulation. The finite element method is applied in the calculation with the load case based on the height of the load on the sideboard, which is equal to 2.96 m, 2.60 m, and 2.24 m. Hence, the size of the deck barge is shown. The length, width, load height, and DWT are 90.44 m, 24.00 m, 5.4 m, 4.2 m, and 10,486 tons, respectively. The sideboard size is also shown in Table 1.

Table 1. The components construction of the sideboard.

<table>
<thead>
<tr>
<th>Components</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dimension</td>
</tr>
<tr>
<td>Stiffener 1</td>
<td>200x70x6</td>
</tr>
<tr>
<td>Stiffener 2</td>
<td>100x70x6</td>
</tr>
<tr>
<td>Stanchion</td>
<td>200x200x8x12</td>
</tr>
<tr>
<td>Support Stanchion</td>
<td>200x200x8x12</td>
</tr>
<tr>
<td>Plate Thickness 1</td>
<td>8</td>
</tr>
<tr>
<td>Plate Thickness 2</td>
<td>10</td>
</tr>
</tbody>
</table>

The type of material used is BKI standard steel with the notation KI-A36 [31], with presented properties. Modulus of Elasticity, Shear Modulus, Poisson Ratio, Density, Yield stress, and Ultimate Stress are 200 GPa, 79.3 GPa, 0.3, 7850 kg / m³, 250 MPa, and 400 MPa, respectively. Figure 1 shows the details of the 2D sideboard construction, which is the object of research—3D modelling using FE with reference to 2D images. 3D modelling is shown in Figure 2.

Figure 1. The object of research.

Figure 2. Inside & Outside view of 3D sideboard with FE.

The next stage is using FE, namely meshing of 3D modelling. It determines how many nodes (points) and elements there are in 3D modelling. The mesh size, number of nodes, and number of elements are 120 mm, 345,672 nodes, and 170,392 elements, respectively. The mesh stages in FE are shown in Figure 3.
The next stage is using FE, which is the input displacement on 3D modelling in the form of fixed support and load according to the load case that was planned at the beginning. The provision of fixed support is shown in Figure 4.

The load input which is the amount of pressure on the sideboard construction is determined based on the active soil pressure of the Rankine method [32] with a sloping ground surface. The pressure that occurs on the sideboard uses the equation (1) for lateral pressure ($P_a$). Therefore, the required variables for each are shown, they are the density of coal ($\gamma$) 8.1634 Kn/m$^3$ [33], load height to the sideboard ($H$), and the active pressure of coal coefficient ($K_A$). Illustration of coal loading case is shown in Figure 5.

$$P_a = \gamma H K_A$$

(1)
The case is where the angle of surcharge of bulk coal [34] is \( (\beta) = 25^\circ \). Anup K Swain provides the angle of internal friction value for bulk coal [35], which is \( (\phi) = 30^\circ \) so that the load given in the FE 3D model is shown in Figures 6, 7, and 8.

\[
K_A = \cos \beta \times \frac{\cos \beta - \sqrt{\cos^2 \beta - \cos^2 \phi}}{\cos \beta + \sqrt{\cos^2 \beta - \cos^2 \phi}}
\] (2)

**Figure 6.** Load case 1 with 2.24 meters.

**Figure 7.** Load case 2 with 2.60 meters.
Fixed support input and pressure on the sideboard will produce the maximum stress of the construction. The stress that occurs is obtained from numerical analysis using the finite element approach [36]. After getting the maximum stress, the next step is to determine the fatigue life of the sideboard construction. The calculation of fatigue life uses the simplified fatigue analysis equation “Fatigue Assessment of Ship Structures” [27]. Then from the maximum stress, we can choose the type of S-N curve to determine the number of cycles. The selection of the S-N curve type is based on the position of the maximum stress, the shape of the weld joint, the type of construction profile section, and the size of the profile section. The basic parameter of loading fatigue is the stress range, in which cracking depends on the number of cycles (S-N diagram) [37]. The S-N curve is shown in Figure 9.

Fatigue life is determined by first calculating the value of fatigue damage using Eq. (3)

$$D = \frac{\nu_0 T_d}{a} q^m r \left(1 + \frac{m}{n}\right) \leq \eta$$ (3)

Fatigue damage

Then, the number of cycles can be calculated using Eq. (4) and Eq. (5)

$$\nu_0 = \frac{1}{4\log_10(L)}$$ (4)

$$q = \frac{\Delta \sigma_0}{(ln n_0)^{\frac{3}{2}} h}$$ (5)
\[ h_0 = 2.21 - 0.54 \log_{10}(L) \]  
\[ h = h_0 + \frac{h_a x z}{T_{act}} - 0.005(T_{act} - z) \]  

\[ \text{Fatigue Life} = \frac{\text{Design Life}}{D} \times \text{years} \]  

\[ \bar{a} = \text{intercept of the design S-N curve with the log N axis}; \quad m = \text{negative inverse slope of the S-N curve}; \quad v_0 = \text{Average zero up-crossing frequency}; \quad n_i = \text{number of stress cycle over time period}; \quad q = \text{Weibull stress range scale distribution parameter}; \quad T_d = \text{Design life of ship in seconds (20 yrs = 6.3 \times 10^8 \text{ sec})}; \quad \Gamma(1 + \frac{m}{n}) = \text{Gamma function}; \quad \text{and Design life = 20 years referred to Det Norske Veritas (DNV) rules.} \]

**RESULTS AND DISCUSSION**

**Research Results**

Sideboard 3D models show predicted stress distributions, and hence the maximum stress positions may be identified. Then the numerical simulation results of FE for each load case are displayed as shown in [Figures 10, 11, and 12].

![Figure 10. Von misses stress of load case 1.](image1)

![Figure 11. Von misses stress of load case 2.](image2)
Figure 10 shows the maximum stress in the X direction at the height of the coal load of 2.24 m against the sideboard of 79.25 MPa. The stresses in the Y and Z directions were insignificant so that they did not have any effect on the sideboard structure. The stress lies in the construction of the stanchions, which are located at the bottom center of the sideboard. The minimum stress detected at the end of the sideboard is 73.925x10^{-11} MPa.

Figure 11 shows the maximum stress in the X direction at the height of the coal load of 2.60 m against the sideboard of 110.11 MPa. The stresses in the Y and Z directions are detected as so small that they do not have any effect on the sideboard structure. The stress lies in the construction of the stanchions, which are located at the bottom center of the sideboard. The minimum stress detected at the end of the sideboard is 11.486x10^{-9} MPa. Whereas Figure 12 shows the maximum stress in the X direction at the height of the coal load of 2.96 m against the sideboard of 146.8 MPa. The stresses in the Y and Z directions were detected as so small that they did not have any effect on the sideboard structure. The stress lies in the construction of the stanchions, which are located at the bottom center of the sideboard. The minimum stress detected at the end of the sideboard is 17.7x10^{-10} MPa.

Discussions

From all three of the load cases to the sideboard, the S-N Curve shape obtained is as shown in Figure 13. The calculation of fatigue life is determined by Eq. (8). Accumulated Fatigue Damage is calculated first using Equations. (3), (4), (5), (6), and (7). The calculation results are shown in Table 2.

Table 2 shows the fatigue damage to the load case on the height of the coal load against the 2.96 m sideboard, which is above 1 (one), which in this condition will cause the structure to fail. Therefore, it is not recommended to apply the load case when the deck barge is operating.
Table 2. The Fatigue Life of Sideboard Construction.

<table>
<thead>
<tr>
<th>Load Height (m)</th>
<th>Number of Cycle</th>
<th>Fatigue Damage</th>
<th>Fatigue Life (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.24</td>
<td>1,000,000</td>
<td>0.25</td>
<td>81.16</td>
</tr>
<tr>
<td>2.60</td>
<td>353,000</td>
<td>0.81</td>
<td>24.72</td>
</tr>
<tr>
<td>2.96</td>
<td>200,000</td>
<td>2.16</td>
<td>9.28</td>
</tr>
</tbody>
</table>

CONCLUSION

From the research conducted, it can be concluded that coal at a load height of 2.24 m against the sideboard has a maximum stress of 79.25 MPa and a fatigue life of 81.16 years. Coal at a load height of 2.60 m against the sideboard has a maximum stress of 110.11 MPa and a fatigue life of 24.68 years. Coal at a load height of 2.96 m against the sideboard has a maximum stress of 146.80 MPa and a fatigue life of 9.28 years. There is an increasing value of stress with the increase of height of the load against the sideboard wall, and there is a decreasing value of the fatigue life with the increase of stress values in the construction. The safe limit of the coal load height on the barge can be referred to in case 2. The load height results in a sideboard age prediction of around 25 years. This is in line with the design life of the barge, which is 25 years. This sideboard age prediction result can be used for sizes under 300 feet.

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