*International Journal of Marine Engineering Innovation and Research, Vol. 7(4), Dec. 2022. 311-320*
*(pISSN: 2541-5972, eISSN: 2548-1479)* 

# Strength Analysis of Towing Hook Support Structure on TB. Khatulistiwa 01

Philipus Valentino[1], Hartono Yudo[2], Ahmad Fauzan Zakki[3]
(Received: 1 November 2022 / Revised: 15 December 2022 / Accepted: 15 December 2022)

***Abstract*— towing hook is one of the important components of a tugboat. Its function is to tow various types of ships, namely containers, tanker ships, and even barges. This activity affects the components to undergo failure and crack, especially the support structure of the hook. Earlier research has analyzed various types of stress characteristics, namely fatigue crack, maximum stress, and maximum factor of safety aimed both at the support structure and the whole profile of the tug. The research aim is to determine the value of stress in the support structure and the safety factor brought by tensile load transferred from the towing hook. The analysis is done using finite element method in Altair Hyper Works 2019. Structural strength of the towing hook support structure is analyzed in 2 loading conditions, namely lightweight barge and full load barge. Two different approaches are used for comparison. The first approach is using barge resistance, and the second is by utilizing maximum tug horse-power to speed ratio. Maximum stress acquired in both loading conditions and both approaches is 118.64 MPa; 121.80 MPa; 230.90 MPa; 329.86 MPa respectively. The safety factor is measured using 2 criteria, BKI permissible stress criterion and BKI Material Strength criterion. Results of safety factors based on BKI permissible stress are 1.644; 1.601; 0.845; and 0.591. According to BKI Material Strength, the safety factors on both loading conditions are 3.371; 3.284; 1.732; and 1.212.**

*Keywords*— finite element method, linear static, tugboat.

## I. Introduction

Indonesia and its vital role as a maritime country are connected to shipping activities, so does the supporting infrastructure. Today, most of the economic activities occur in coastal areas, such as shipbuilding, stevedoring in port and harbors, and many more. Stevedoring and other port-related tasks demand high speed and high efficiency. Numerous ships must be handled in limited time to keep the activity going throughout the day. In order to handle this, tugboats are one way to answer the problem. Tugboats are useful to tow or push large vessels in the densely-packed waterway. These tugboats are commonly equipped with a towing hook and a towing winch to help with its task.

Analysis of towing hook support structure has been conducted several times with different loading conditions. Previous research has been conducted to analyze main deck structure fatigue life and critical stress point. The analysis resulted in 19.61 years of fatigue life and critical stress point with magnitude of 149 MPa in node 4390[1].

Similar research has been conducted to calculate local stress value using a finite element method (FEM). The research is based on a four-loading case of barge, namely lightweight barge, lightweight barge + dead weight barge, sagging (full load), and hogging (full load). Maximum stress value is 78.30 MPa at node ID 23279, occurs in sagging-full load condition [2].

Towing hook strength analysis is done towards TB. Asia Tirta 2005, measuring load and fatigue life prediction with a three-loading condition, known as 100%, 75%, 50% of tugboats displacement. Result of fatigue life prediction is 22 years, 22 years, and 23 years respectively [3].

On similar research conducted to 400 HP Tugboat named TB. Ari, analysis was done to ac-quire different stress value in different loading conditions. Highest stress value noted was the barge-pushing maneuver on a lightweight barge with magnitude of 42.6 MPa, whilst dead weight barge loading condition resulted 147 MPa. The towing maneuver on both conditions (lightweight and dead weight barge) recorded value are 79.1 MPa and 191 MPa respectively [4].

The practice of towing hooks in tugboats and barges are still common in maritime industry thus making this a very good background for similar research. Furthermore, there are different types and towing hook support structures found in different ships.

Based on several considerations, one has decided to conduct research titled "Strength Analysis of Towing Hook Support Structure on TB. Khatulistiwa 01". Furthermore, this research is limited by scope of work as mentioned as following:

1. The analysis is done using only TB. Khatulistiwa 01 as the object.
2. Modeling and analysis are done with the finite element analyses (FEA)-based software.
3. Analysis type is limited to linear static.
4. Calculations included are: maximum stress, factor of safety of towing hook support structure.
5. The materials of the tow rope (sling) are negligible.
6. Fatigue life prediction is not included in the research.

Philipus Valentino is with Department of Naval Architecture, Universitas Diponegoro, Semarang, 50275, Indonesia. E-mail: philipus.valentino@student.undip.ac.id

Hartono Yudo is with Department of Naval Architecture, Universitas Diponegoro, Semarang, 50275, Indonesia. E-mail: hartono.yudo@yahoo.com

Ahmad F. Zakki is with Department of Naval Architecture, Universitas Diponegoro, Semarang, 50275, Indonesia. E-mail: ahmadfzakki@yahoo.com

The research aim is to calculate the maximum value of towing hook support structure on TB. Khatulistiwa 01 and the factor of safety of the structure which is acquired from comparison of acquired tow load and maximum yield stress.

**Figure. 1**. Illustration of towing barge

**Figure. 2**. TB Khatulistiwa 01

## II. METHOD

### *A. Research Object*

#### *A.1 Tugboat*

Tugboat or tugs are a special purpose ship because of its specific function. It serves other larger vessel, mostly in port and harbor waterway, inland waterway, and even off-shore purpose. Most of the ship type is able to be towed/pushed by tugboat, such as container vessel, bulk carrier, oil tanker, and even offshore drill facility. This purpose makes tugboat commonly equipped with higher horse power compared to its size. According to its service area, tugboat is categorized into the following [5]:

a) Ocean Going Tug
b) Coastwise and Estuary Tug
c) Estuary and Harbor Tug
d) Shallow Draught Pusher Tug
e) River and Dock Tug

The object for the research is a river tug with callsign “Khatulistiwa 01” owned by PT. Jasa Armada Indonesia.

#### A.2 *Towing Hook*

Towing hook is one of the most common equipment found in tugboat. It holds line that connects from the tugboats to the towed vessel. According to BKI 2nd Volume, Section 27 about Tugs [6], towing hook is recommended to have safety design such as quick release mechanism. It is regulated specifically so that in event of line breaks down, the crew and the ship remain safe. Another feature of the towing hook is the spring that absorb shock loading during the process.

Generally, a tugboat maneuver is likely to experience external forces (wave, wind, current) and internal forces (wave by propeller and reaction of the towed barge. There is almost none effect of wave forces in tugboat operation, yet the vertical motions might impact tugboat and force prediction analysis. Tugboat force prediction should be conducted in calm and fair environment, with minimal currents and wind [7].

Towing hook function is to hold static and dynamic loading caused by towing activity. It is installed on a support structure stiffened by bolts or welded joints. It has to fulfill certain stress criteria, such as extreme loading conditions. While these criteria are usually non-linear, the most common approach used is by finite element based- approach.

The three-dimensional model used in the current research is created from a two-dimensional (2-D) drawing of towing hook and its support structure.

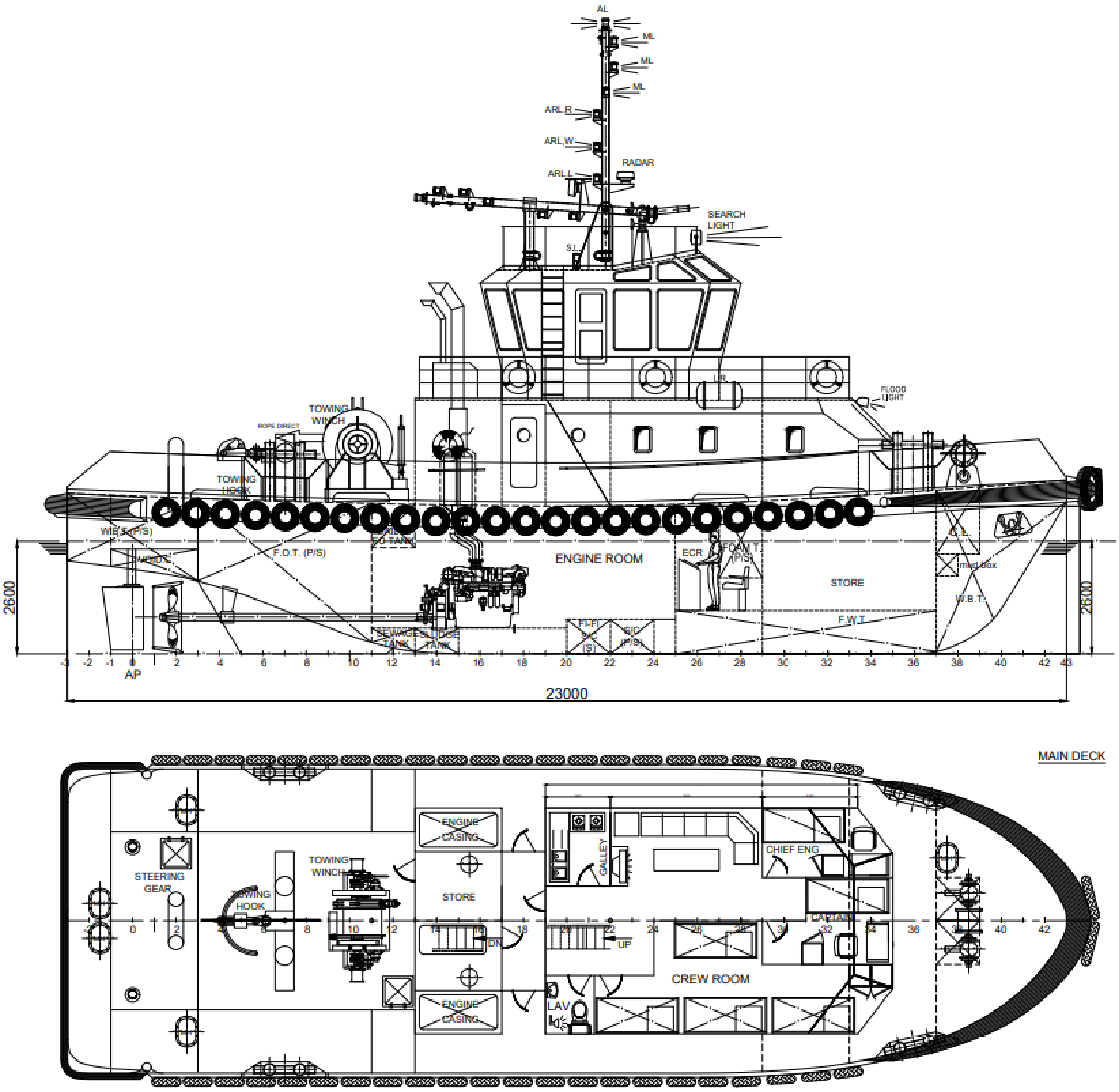


**Figure. 3**. General Arrangement of TB. Khatulistiwa 01

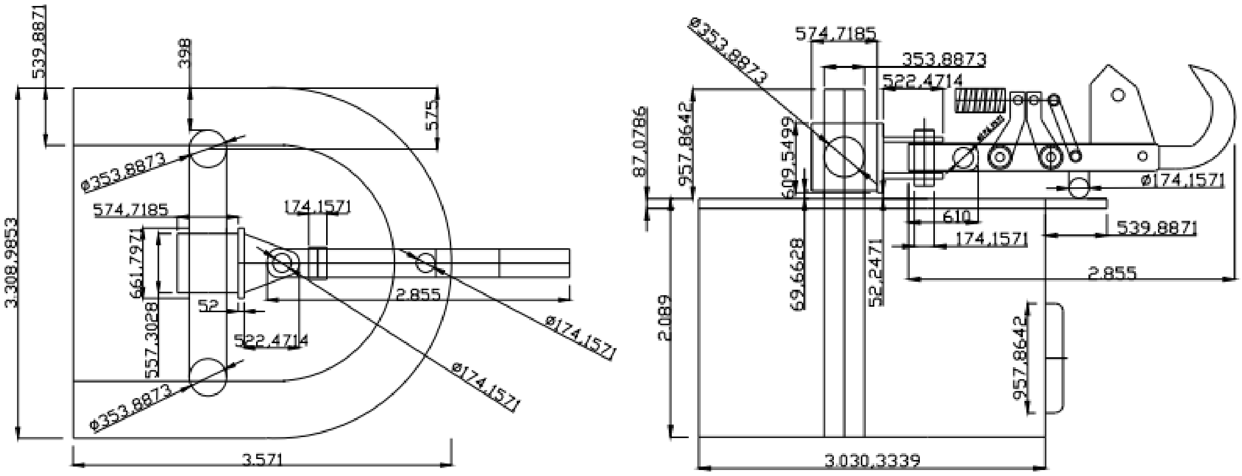


**Figure. 4.** Detail Drawing of Towing Hook Support Structure

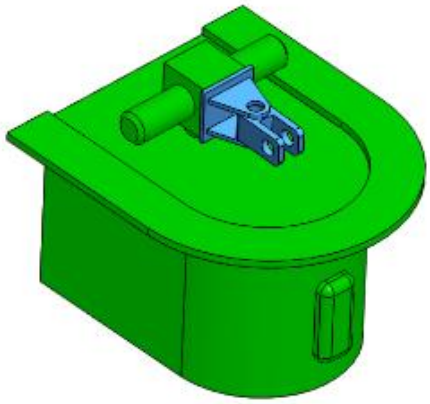

**Figure. 5**. 3d Model of Towing Hook Support Structure

*B. Stress*

Stress is a condition whenever an external force is applied on a body then a resisting force in induced in a body. It is also defined as the ratio of applied load to the cross-section area of the body.

According to mechanics of materials, it is needed to determine the intensity of these forces on the various portions of a section as resistance to deformation and to forces depends on these intensities. of working forces acting on the body. There are two (2) types of stress: normal and tensile stress. Mathematically, stress is written in the following equation [8]:

$$\sigma = \lim_{\Delta A \to 0} \frac{\Delta F}{\Delta A} \quad (1)$$

where:

σ : Stress

F : resisting force perpendicular to cross-section body.

A : cross-section area of the body

*C. Strain*

The concept of strain is a condition when an external force is applied on the body followed by some change of dimension of the body. It is a dimensionless quantity as it describes the ratio of changed dimension (L1) and original dimension (L0). There are various types of strain, namely: tensile strain, compressive strain, volumetric strain, and shear strain[9]. Mathematically, strain is expressed as follows:

$$\varepsilon = \frac{\Delta L}{L} \quad (2)$$

where:

ε : strain

ΔL : gauge length elongation

L : initial gauge length

TABLE 1.
PRINCIPAL DIMENSION OF TB. KHATULISTIWA 01

| Dimension | Value |
|---|---|
| Length Over All | 23.0 m |
| Breadth | 7.0 m |
| Depth | 3.4 m |

| | |
|---|---|
| Draft | 2.6 m |
| Speed | 10 knots |
| Complement | 10 *persons* |
| Engine Power | 2 x 600 HP |
| Bollard Pull | 12 ton |

*D. Finite Element Method*

Finite element method poses one of the most used methods of numerical analysis in structural analysis, including maritime industries. It is commonly used to understand and solve elasticity problems in marine structures. Finite Element Analysis (FEA) is a name for calculations and problem-solving using finite element-based software. FEA start with modeling a body of structure, setting up boundary and loading conditions, and meshing the geometry [10]. Several widely known FEA software are as follows: MSC Nastran, Altair Hyper Works, Simulia Abaqus, ANSYS™.

*E. Factor of Safety*

The factor of safety (F.S.) is a capacity of a system which determines the load-carrying capacity beyond its actual load. Factor of safety is needed to ensure the applied load is less than the load of a body can fully support. Specific values of F.S. depend on the types of materials. According to BKI, Safety factor should be greater than one (>1). Factor of safety is acquired by dividing maximum stress load to allowable stress load. Mathematically, the F.S. is described as follows:

$$FS = \frac{\sigma_{max}}{\sigma_y} \quad (3)$$

where:
$\sigma_{max}$ : maximum stress load
$\sigma_y$ : permissible stress load

According to Rules for Hull, Section 27 C3, permissible stresses should not exceed with assumption a load equal to minimum breaking force of the towrope. Mathematically, it is written as follows [6]:

$$\sigma_y = 0.83 \times R_{EH} \quad (4)$$

where:

$R_{EH}$ = yield strength 235 N/mm$^2$

## III. Results and Discussion

*A. Calculation of Tugboat Towing Force*

Initial calculations used an assumption where barge is towed by a tugboat with following details taken from Table 1:

Speed = 10 knots
Bollard Pull = 12 tons
Horse Power = 2 x 600 HP

Thus, the data is converted to MPA units for further analysis and calculation.

Since 1 ton-force = 9,806.65 N,

Then,

$$BP = \frac{12 \text{ ton } force}{1} \times \frac{9.806{,}65\ N}{1\ ton\ force}$$
= 117,679.8 Newton

Similar conversion method also applied to Horse Power (HP) to kilowatt (kW) unit with following equation:

Since 1 HP = 0.7457 kW

Then,

$$HP = \frac{1.200\ HP}{1} \times \frac{0.7457\ kW}{1\ HP}$$
= 894.94 kW

Given value of the converted bollard pull and maximum engine power are used later to determine the maximum towing force of the tugboat.

*B. Calculation of Barge Towing Load*

Towing load of barge is calculated by given resistance value taken from MAXSURF Resistance. Given the principal dimension of the towed barge as shown in Table 2.

Consideration is taken from given data of bollard pull and maximum power, maximum value of towing load in both loading conditions are shown in Table 3 and 4.

*C. Material Properties of Towing Hook Support Structure*

The material used in the structure is a marine steel plate with KI-A36 Standard [11] shown at Table 5.

*D. Structure 3-D Modeling*

The 3-D Model is designed with finite element-based software. The modeled part are the component block supporting the towing hook. The towing hook itself is not modeled thus replaced by a constraint that holds static load.

*D.1 Material Definition*

Material given in this research is industrial KI-A36 Steel with details shown in Table 2. Properties of material is given after components are connected in assembly process.

*D.2 Boundary Condition*

Analysis using finite element approach needs a support point acts as pedestal, known as boundary condition. The boundary conditions have several functions as described in the following [12]:
1). Determine the value of displacements in a specific region of the model
2) Represent loads in a specific region of the model
3) Simplify part that is not modeled.
There are several types of boundary conditions, namely the following[12]:

a) Constraint, works to remove an equation from stiffness matrix
b) Loading, used to represent input to FEA model, i.e., gravity, force, moment, velocity, acceleration.
c) Contact, a boundary condition to define interaction between components

Boundary conditions are set below the surface of support span with 6 degrees of freedom fixed on point.

*D.3 Meshing*

Meshing is a discretization process to reduces the number of infinite degrees of freedom to finite numbers by creating smaller elements and nodes on surfaces and solids of the model geometry.

TABLE 2.
PRINCIPAL DIMENSION OF TOWED BARGE

| Dimension | Value |
|---|---|
| Length Over All | 91.44 m |
| Breadth | 24.8 m |
| Depth | 6.1 m |
| Load Draft | 4.9 m |
| Light Draft | 1.06 m |
| Classification | BKI |
| Max. loading | 7 ton / $m^2$ |

TABLE 3.
TOWING LOAD BY RESISTANCE VALUE

| Load | Speed (kn) | KR Barge Resistance (N) | KR Barge Power (kW) |
|---|---|---|---|
| LWT | 5.75 | 108,256.05 | 320.227 |
| Full Loading | 3.50 | 110,919.86 | 199.717 |

TABLE 4.
TOWING LOAD BY RESISTANCE VALUE

| Load | Speed (kn) | KR Barge Resistance (N) | KR Barge Power (kW) |
|---|---|---|---|
| LWT | 8,00 | 209.554,25 | 862,432 |
| Full Loading | 5,75 | 299.370,43 | 885,554 |

TABLE 5.
MATERIAL PROPERTIES OF KI A-36 STEEL

| Criteria | Value | Units |
|---|---|---|
| Elastic Modulus (Young) | 210 | Gpa |
| Shear Modulus | 79.3 | Gpa |
| Yield Strength | 250 | Mpa |
| Ultimate Strength | 400 | Mpa |
| Density | 7850 | $kg/m^3$ |
| Poisson’s Ratio | 0.33 | |

Meshing technique used in this research is 3-D meshing with a hexahedral element shape. Size of the elements of smaller components (colored in blue, see Fig. 6) and base support structure (color in red, see Fig. 6.) undergoing in auto mesh process is 25 and 50 cm respectively.

The following process determines the element properties among individual components. Considerations used to determine the properties of each element is based on size ratio (length to width, thickness to length). Thus, the elements are classified into 1-dimensional elements, 2-dimensonal elements, and 3-dimensional elements.

Components in towing hook support structure is divided into 3-D elements (solids) and 2-D elements, (shell). Final model of mesh geometry is shown Figure 6.

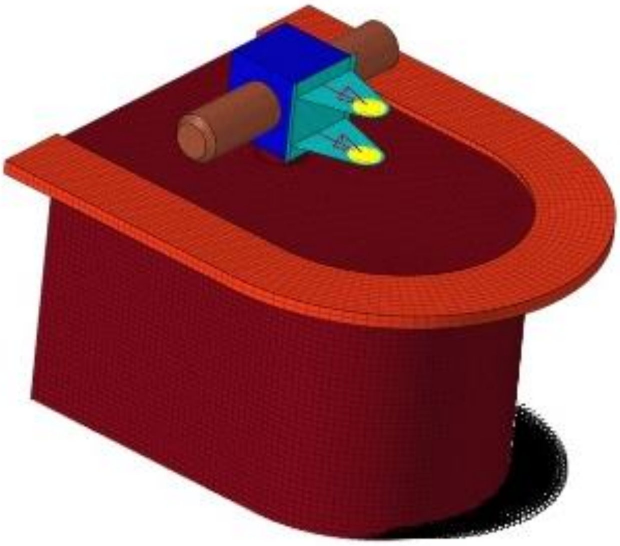

**Figure. 6.** Solid meshing in towing hook support structure

*E. Loading Assumption*

Research conducted to calculate maximum stress value is limited to linear static analysis in two given loading case, namely light weight barge and full loading condition. The barge was towed in a fair inshore condition with the minimum wave and minimum current state. Towed vessel is a deck cargo barge is with $0^0$ towing angle (straight line) at given forward speed.

*F. Analysis Result*

Research is conducted with preset conditions gives the following results:

*F.1 Light Weight Barge*

First condition of LWT Barge is subjected to static tow loading of 108,256.05 N. Maximum stress value of 118,64 MPa is recorded at element ID 195930 shown in figure 7.

*F.2 Full Load Barge*

Second condition is Full load barge subjected to static tow loading of 110,919.86 N. Maximum stress value of 121,8 MPa is recorded at element ID 195930 shown in figure 8.

*F.3 Towing Load by Ship Horse Power*

This analysis simulates towing load using given resistance at maximum horsepower available – below 1200 HP (894.94 kW).

a) Full Loading
Towing load at Full loading barge in maximum horsepower available at 885.554 kW is 299,370.43 N. Maximum stress value of 329,86 MPa is recorded at element ID 196005, shown in figure 9.

b) Light Weight Barge
Towing load at Lightweight barge condition in maximum horsepower available (862.432 kW) is 209,554.25 N. Maximum stress value of 230.90 MPa is located at element ID 196005 shown by figure 10.

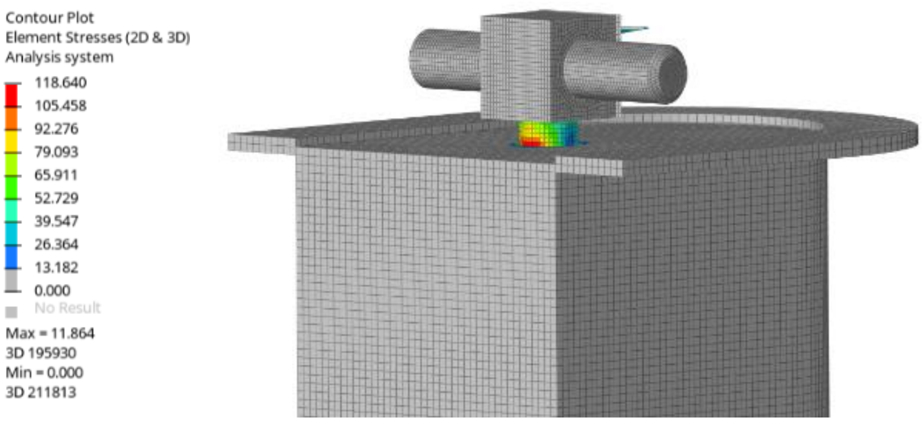


**Figure. 7.** Critical stress point of towing hook support structure, lightweight barge condition

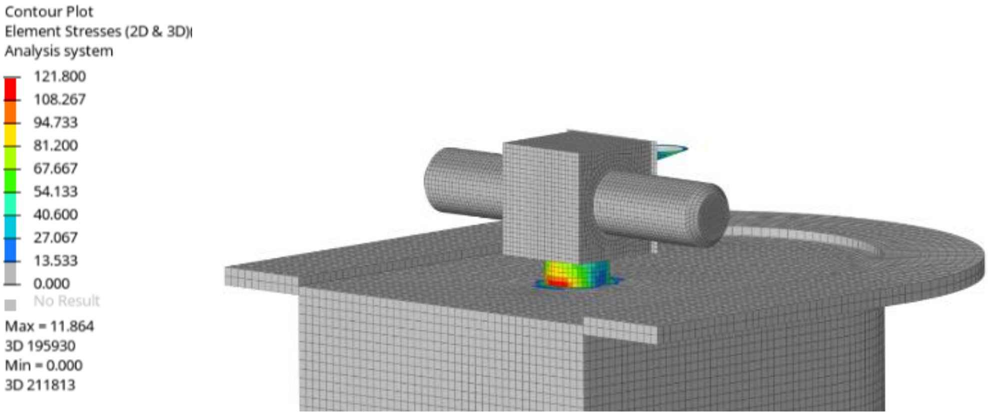


**Figure. 8.** Maximum stress value of towing hook support structure, full loading condition.

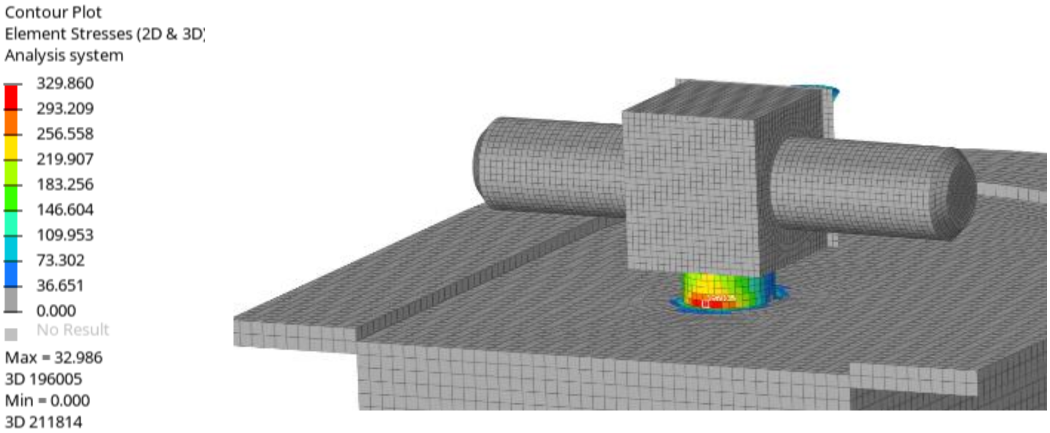


**Figure. 9.** Maximum stress value of the structure, full loading condition, maximum horsepower.

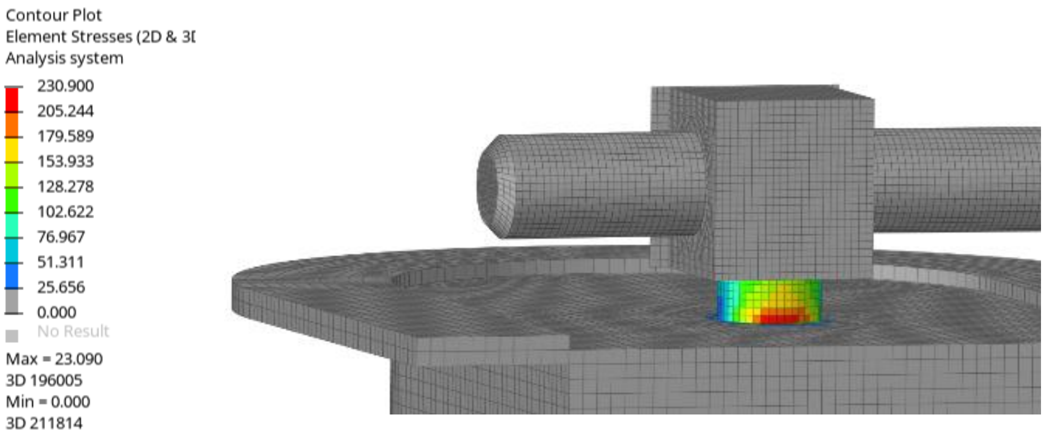


**Figure. 10**. Critical stress point of towing hook support structure, lightweight barge condition

*G. Safety Factor*

Calculations of safety factor is done based on two criteria, BKI permissible stress value and BKI material strength. The permissible stress criteria states that the towing hook foundation should not exceed value of 195.05 MPa (equivalent stress of KI-A36 yield strength. The second criterion is based on the material's maximum strength with value of 400 MPa. Calculations of safety factor is given in Table 6 and 7. Safety factor calculation on various loading conditions based on BKI Permissible Stress criteria highlight 2 different results. In lightweight barge loading condition, both calculation (LWT and Full Load) with barge resistance approach passed the permissible stress limit, given 1.644 and 1.601 of safety factor.

However, a different approach using maximum tug horsepower do not pass the safety factor criteria, given 0.845 at LWT barge and 0.591 at full loading barge. This points out that higher horsepower leads to higher resistance, thus add significant towing load to the support structure.
The calculation passes the second criterion, BKI Material Strength of 400 MPa, given safety factor value of 3.371 and 3.284 at LWT and full loading condition. Maximum tug horsepower approach did pass the criterion, with safety factor of 1.732 and 1.212 on LWT and full loading barge, respectively.

TABLE 6.
SAFETY FACTOR BY BKI PERMISSIBLE STRESS CRITERION

| Load | $\sigma_{Max}$ (Mpa) | Element ID | $\sigma_{permissible}$ (Mpa) | SF | Mark |
|---|---|---|---|---|---|
| *LWT* | 118.64 | 195930 | 195.05 | 1.644 | *Pass* |
| *Full Load* | 121.80 | 195930 | 195.05 | 1.601 | *Pass* |
| *LWT (Max HP)* | 230.90 | 196005 | 195.05 | 0.845 | *Fail* |
| *Full Load (Max HP)* | 329.86 | 196005 | 195.05 | 0.591 | *Fail* |

TABLE 7.
SAFETY FACTOR BY BKI MATERIAL STRENGTH CRITERION

| Load | $\sigma_{Max}$ (Mpa) | Element ID | $\sigma_{permissible}$ (Mpa) | SF | Mark |
|---|---|---|---|---|---|
| *LWT* | 118.64 | 195930 | 400 | 3.371 | *Pass* |
| *Full Load* | 121.80 | 195930 | 400 | 3.284 | *Pass* |
| *LWT (Max HP)* | 230.90 | 196005 | 400 | 1.732 | *Pass* |
| *Full Load (Max HP)* | 329.86 | 196005 | 400 | 1.212 | *Pass* |

## IV. CONCLUSION

Strength analysis of towing hook support structure on TB. Khatulistiwa 01 with loading conditions gives the following conclusions:

Analysis with barge resistance approach gives maximum stress of 118.64 MPa and 121.80 MPa, recorded at element ID 195930, on both LWT and Full loading conditions, respectively. Whilst maximum tug horse-power approach gives maximum stress of 230.90 MPa and 329.86 MPa recorded at element ID 196005.

Safety factor of 1.644; 1.601; 0.845; and 0.591 are obtained based on BKI permissible stress criterion with both approach and loading condition, respectively (barge resistance and maximum tug horsepower). Safety factor of 3.371; 3.284; 1.732; and 1.212 are based on BKI material strength criterion, respectively. Thus, given safety factor less than one (<1) on the maximum tug horse-power approach should not be conducted as it is considered unsafe and did not guarantee the safety of the towing hook support structure.

## ACKNOWLEDGEMENTS

The research has been made possible with the support of PT. Jasa Armada Indonesia Tbk, CAMY-Labotech, and other parties involved in conducting the research.

## REFERENCES

[1] A. P. Rizky, I. P. Mulyatno, and S. Joko Sisworo, “Analisa Fatigue Kontruksi Main Deck sebagai Penumpu Towing Hook akibat Beban Tarik pada Kapal Tug Boat 2 x 800 HP dengan Metode Elemen Hingga,” J. Tek. Perkapalan, vol. 4, no. 1, pp. 190–198, 2016.
[2] L. Damanik, I. P. Mulyatno, and B. Arswendo, “Kajian Teknik Kekuatan Konstruksi Kapal Tugboat 2 X 800 Hp Dengan Metode Elemen Hingga,” J. Tek. Perkapalan, vol. 4, no. 1, pp. 113–122, 2016.
[3] L. P. Adnyani, M. A. M. Arsyad, and S. Dlukha, “Analysis of Fatigue Life of Tugboat Towing Hook Construction Using Finite Element Method,” Kapal J. Ilmu Pengetah. dan Teknol. Kelaut., vol. 17, no. 2, pp. 86–94, 2020.
[4] N. Maranata, I. P. Mulyatno, and W. Amiruddin, “Analisa Kekuatan Konstruksi Kapal Tugboat Ari 400 Hp Dengan Metode Elemen Hingga,” J. Tek. Perkapalan, vol. 3, no. 1, pp. 118–126, 2015.
[5] K. van Dokkum, Ship Knowledge a Modern Encyclopedia. Meppel: DOKMAR, 2003.
[6] Biro Klasifikasi Indonesia, Rules for Hull, vol. II. Jakarta: BKI, 2021.
[7] R. D. Barrera, L. A. Schiaveto Neto, D. P. Vieira, E. S. Mesquita, and E. A. Tannuri, “Azimuth stern drive (ASD) vector tugs positioning and towing force prediction during docking, steering and braking maneuvers,” Applied Ocean Research, vol. 110. 2021.

[8] R. C. Hibbeler, Mechanics of Materials, 10th ed. Hoboken: Pearson, 2015.
[9] E. P. Popov, Mechanics of Materials, 2nd ed. Englewood Cliffs, NJ: Prentice Hall, 1978.
[10] A. F. Zakki, Metode Elemen Hingga. Semarang: Lembaga Pengembangan dan Penjaminan Mutu Pendidikan UNDIP, 2014.
[11] Biro Klasifikasi Indonesia, Rules for Materials, vol. V. Jakarta: BKI, 2019.
[12] D. Madier, Practical Finite Element Analysis For Mechanical Engineers. Ontario: FEA Academy, 2020.