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# Maximum Stress Analysis on Ship Anchor Chains with Various Force Angles

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**ABSTRACT**

One of the components of ship fittings is the anchor chain. Usually, when the anchor is moored, it is not always positioned perpendicular to the ship's hull; instead, it often forms an angle between the chain and the hull. Due to environmental influences or excessive tension occurring at certain angles, there have been cases of anchor chains breaking. Therefore, it is necessary to conduct a maximum stress analysis of the ship's anchor chain with varying force angles to determine the maximum stress experienced by the chain. This research focuses on the anchor chain of the Tug Boat Marina 2435 and utilizes ANSYS Workbench for finite element analysis. In this research, the chain is suspended from the hawse pipe with a diameter of 19 mm, and the loading on the anchor chain is static, consisting of the weight of the chain and the anchor. The angles analyzed are 30°, 35°, 40°, 45°, 50°, 55°, and 60°. The maximum stress on the anchor chain was observed at an angle of 35°, with a value of 6.9943 MPa. The stress at each angle remained below the ultimate tensile strength of the material, which is 515 Mpa.



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## INTRODUCTION

Maritime transportation services are certainly familiar with sea vessels. Ships are essential for inter-island transportation between regions and islands in Indonesia, considering that Indonesia has a larger sea area compared to its land area. Nowadays, ships are not only used for transportation services but are designed in various configurations to serve distinct functions. Examples include fishing vessels used by fishermen, cruise ships, cargo ships carrying various types of loads, coal barges, tug boats, and many other types of ships worldwide. A tug boat is a vessel used to assist in pushing or pulling other ships in ports, open seas, and rivers. Additionally, this type of ship is often used to tow barges, damaged ships, and various other marine equipment (Ghofur et al., 2022). Tug boats have greater power relative to their size because they are specifically designed to help larger ships dock or depart from ports (Hisrian, et al., 2016).

Although tug boats are primarily used to assist other ships, they must be equipped with ship fittings that comply with applicable regulations and classification standards (Biro Klasifikasi Indonesia, 2025, 2022; Chakrabarti, 2005; IACS, 2020). One of the essential ship fittings is the anchor. An anchor serves to hold the ship in position, preventing it from drifting when moored or docked at a port (Dwiatma et al., 2019). The chain acts as a connecting device between the anchor and the ship. The length of the chain varies depending on the size of the ship and the anchor (Hutama et al., 2016).

To raise and lower the anchor on a ship, a mooring system is used. This system is designed to secure the ship at the dock or open sea, preventing movement caused by currents, wind, and waves. Typically, when the anchor is moored, these environmental forces cause the chain to form an angle with the ship, resulting in tension that can sometimes be excessive. Excessive tension caused by the chain angle can lead to the risk of chain failure, which endangers both the crew and the ship. Therefore, it is necessary to analyze the maximum stress on the ship's anchor chain with varying force angles to determine the maximum stress value (Putera et al., 2021).

The objective of this study is to determine the maximum stress on the ship's anchor chain with varying force angles. The anchor chain analyzed in this study belongs to the Tug Boat Marina 2435, with a diameter of 19 mm. The chain is suspended from the hawse pipe on the starboard side of the ship, with a length of 1,330 mm. This study employs AutoCAD and ANSYS software (Utomo et al., 2024). AutoCAD is a design application developed by Autodesk, widely used by students, especially those in engineering faculties, for modeling and design purposes. ANSYS is a software application used to perform various engineering simulations and designs to obtain results such as stress, strain, deformation, and others. This study utilizes ANSYS Workbench, a finite element method (FEM)-based simulation tool for engineering problem analysis (ANSYS, 2010). The typical stages in this analysis include defining material properties, meshing, setting boundary conditions, applying forces, selecting solution types, and obtaining results such as stress and deformation (Hamidah et al., 2018).

Two previous studies underpin this research, both employing FEM-based software methods. These studies focus on environmental stresses on anchor chains (Arifannisa, 2016), identifying the joint area as a critical region with a maximum stress of 235.39 MPa for the rotation component at a chain angle of 4°. The maximum deformation value of 0.340 mm occurs at the rotating part at a

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flat chain angle of 5°. The stress values under various load changes remain below the yield strength of the material used, which is 680 MPa, with a minimum safety factor of 2.89. These findings provide a foundation for the current finite element method study.

## METHOD

The research method is a scientific approach used to obtain data with the aim of describing, proving, developing, and discovering knowledge or theories to understand, solve, and anticipate problems in human life. The research approach employed in this study is quantitative, using an experimental method on the anchor chain angles subjected to loads (Li et al., 2024), analyzed through finite element-based software, namely ANSYS (Arifannisa, 2016).

This study uses the anchor chain from the Tug Boat Marina 2435. The required data includes the diameter of the anchor chain, the material properties of the chain, and the weight of the load, which is the ship's anchor. The chain diameter and anchor weight data were obtained from the BKI website and directly measured at PT. Industri Kapal Indonesia (Persero) Makassar. Figure 1 presents the main steps involved in the anchor chain stress analysis process.

## RESULTS AND DISCUSSION

### Material

The material used in this study is an AISI Type 316L stainless steel. This material was chosen because it is a low-carbon stainless steel, which is commonly used for anchor chain materials on medium-sized ships such as tug boats. Low-carbon stainless steel offers excellent corrosion resistance (Mardawiah, 2021) and mechanical properties suitable for marine applications described at table 1.

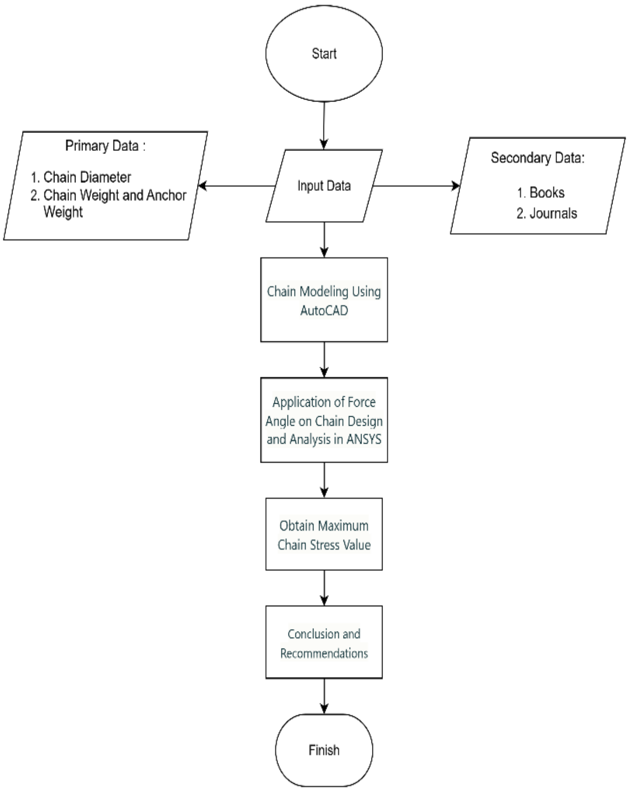


**Figure 1. Flowchart**

**Table 1. Material properties of anchor chain**

| Properties | Value |
|---|---|
| Ultimate Tensile Strength | 515 MPa |
| Tensile Yield Strength | 205 MPa |
| Shear Modulus | 76923 MPa |
| Young's Modulus | 2e+05 MPa |
| Elongation (%) | 60 |

### Anchor Chain Modeling Using AutoCAD

Based on data obtained from the official BKI website, the Tug Boat Marina 2435 has an anchor chain diameter of 19 mm, referring to the description rules for studless link chains according to BKI Rules Volume V, Part I, Section 13. According to these rules, the chain dimensions are specified as 7d in length and 4d in width, which means that for a diameter of 19 mm:

- Chain length, 7d = 7 × 19 = 133 mm
- Chain width, 4d = 4 × 19 = 76 mm

Using these dimensions, the anchor chain was modeled in AutoCAD software to produce both 2D and 3D representations with a diameter of 19 mm as shown on Figure 1, for viewing 2D angle for model anchor chain shown on Figure 2 and viewing 3D angle for model anchor chain shown on Figure 3.

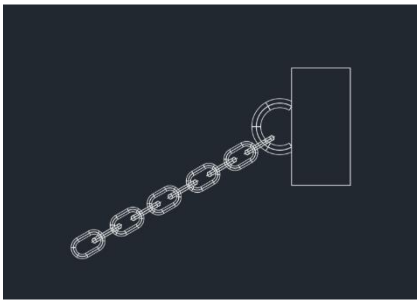

**Figure 2. 2D Model of anchor chain at 30 degrees**

**Figure 3. 3D Model of anchor chain at 30 degrees**

Determination of Maximum Stress on the Anchor Chain. The analysis of the maximum strength of the anchor chain was conducted using ANSYS software. The stages involved in this analysis include defining material properties, meshing, applying loads, selecting the solution type, and obtaining results in the form of maximum stress. Based on field data, the Tug Boat Marina 2435 has an anchor chain diameter of 19 mm. According to BKI regulations, the chain weight is 7.9 kg/m, and this study uses 10 studless links. Therefore, the total weight applied in this study consists of the weight of 10 studless links plus the weight of the ship's anchor. The anchor weight is known to be 368 kg. Hence, the load applied in the analysis is 4383.5949 N. Load total for this research shown on table 2.

**Table 2. Load total**

| Load | kg/m | Newton |
|---|---|---|
| 1 Chain Link | 7.9 | 77,4729 |
| 10 Chain Links | 79 | 774,7293 |
| Anchor | 368 | 3.608,8656 |
| Total Load | 447 | 4.383,5949 |

**Process Analysis System**

The first step in analyzing strength and deformation using ANSYS Workbench is to define the analysis system. In this study, the Static Structural analysis system is used. Static Structural is suitable for determining stress and deformation under static loads. Within the Static Structural module, there are several components including engineering data, geometry, model setup, solution, and results.

**Engineering Data**

Next step is inputting the engineering data. Engineering data contains information about the material to be used. In this study, the material used is AISI Type 316L stainless steel, where material properties such as ultimate tensile strength, yield strength, and others are input into the engineering data.

**Geometry**

The next step after defining the material properties is to import the drawing created in AutoCAD. The procedure is to right-click on the Geometry cell, then select the option to import the design file that has been previously exported. After importing the geometry, right-click on the outline import and select Generate to display the design.

**Model**

Next, the material assignment is verified

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into the design. Then, the meshing process is carried out, which involves dividing the component to be analyzed into small or discrete elements. During this stage, mesh convergence is performed to determine the appropriate mesh size that can be used as a reference for calculating the maximum stress on the chain. The mesh convergence size used in this study is 19 mm. After specifying the mesh size, click Generate Mesh. Detai mesh convergence results shown on table 3, for mesh convergence graph shown on figure 4 and for display results meshing in Ansys shown on figure 5.

**Table 3. Mesh convergence results**

| *No.* | *Mesh Size* | *Stress (MPa)* | F (N) |
|---|---|---|---|
| 1 | 10 | 6.7599 | 4.383,5949 |
| 2 | 12 | 5.6526 | 4.383,5950 |
| 3 | 14 | 5.9077 | 4.383,5951 |
| 4 | 16 | 6.9943 | 4.383,5952 |
| 5 | 18 | 6.3952 | 4.383,5953 |

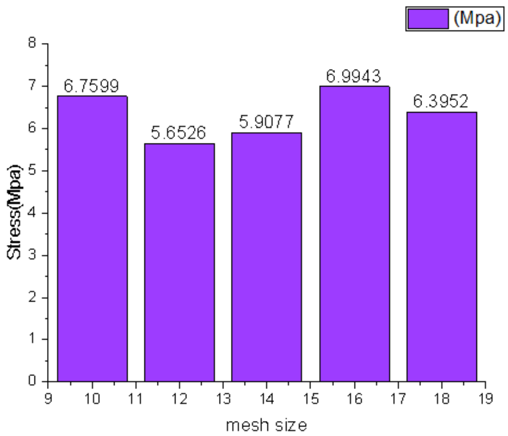


**Figure 4. Mesh convergence graph**

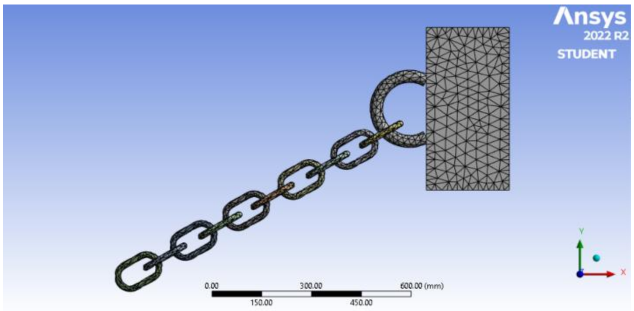


**Figure 5. Object meshing**

**Setup**

The next step is the setup stage, where the load is applied to the design. To do this, right-click on Static Structural, then select Insert and choose Force. Next, select the part of the design where the force will be applied. In this study, the force is applied to 10 chain links. Under the Define By option, select Components, then enter the load value derived from the combined weight of the anchor and chain, which is 4383.5949 N. For display force in Ansys shown at figure 6.

After applying the force, define the Fixed Support on the design. In this study, the fixed support represents a simple beam with a ring that functions to attach the chain. The steps to assign the fixed support are similar to those for applying the force: right-click on Static Structural, select Insert, then choose Fixed Support, and select the appropriate geometry area to fix. For display fixed support in Ansys shown at figure 7.

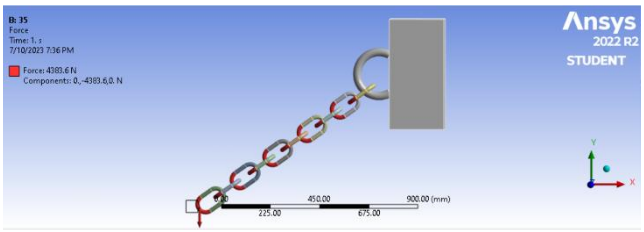


**Figure 6. Force**

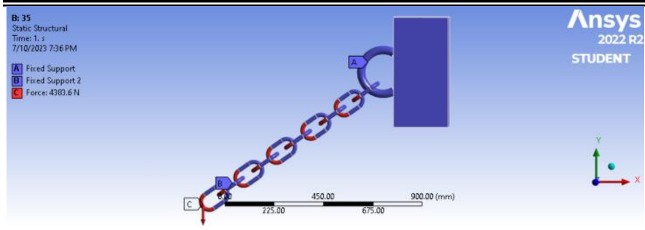


**Figure 7. Fixed support**

## Solution

The next stage is the solution phase, where the desired analysis results are selected. The procedure is to right-click on the solution outline and then click Insert. Several analysis options will appear; however, in this study, only the maximum stress is sought. Therefore, the Maximum Principal Stress is selected. The angle range of 30°–60° was selected based on the assumption of typical operational conditions encountered in tugboat anchoring, as well as standard guidelines for mooring systems. This study assumes static loading, which may oversimplify real anchor chain behavior. In practice, dynamic effects from waves, currents, and vessel motion can influence stress distribution.

The analysis results for anchor chain angles of 30°, 35°, 40°, 45°, 50°, 55°, and 60°, subjected to a static load of 4383.5949 Newtons, were obtained using a mesh size of 14 mm. The overall trend of maximum stress values across these angles is presented in Figure 8. The highest maximum stress was found at an angle of 35°.

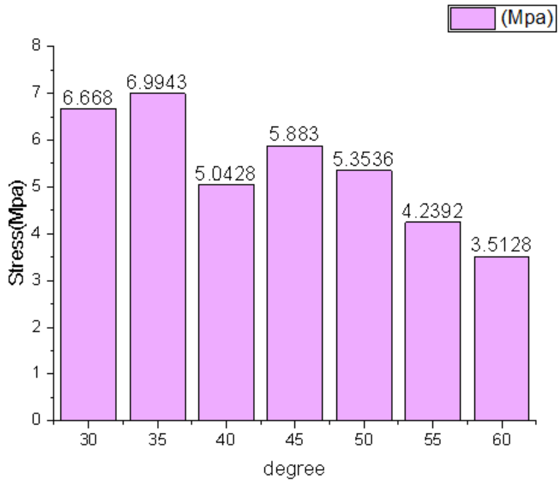


**Figure 8. Analysis result graph**

The results of the maximum chain stress simulation in ANSYS are as follows:

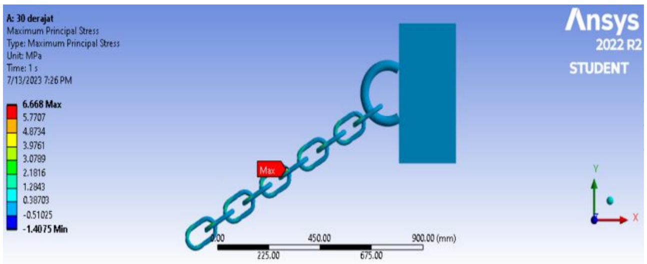


**Figure 9. Simulation result at 30 degrees**

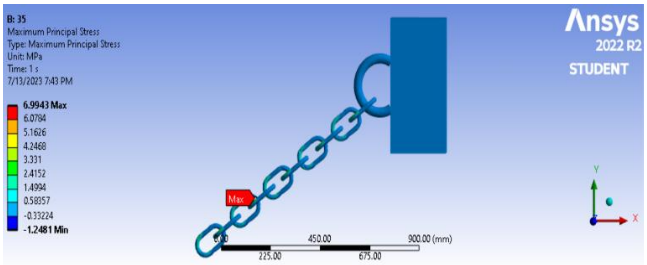


**Figure 10. Simulation result at 35 degrees**

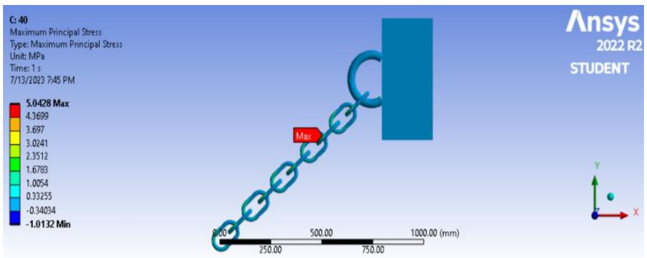


**Figure 11. Simulation result at 40 degrees**

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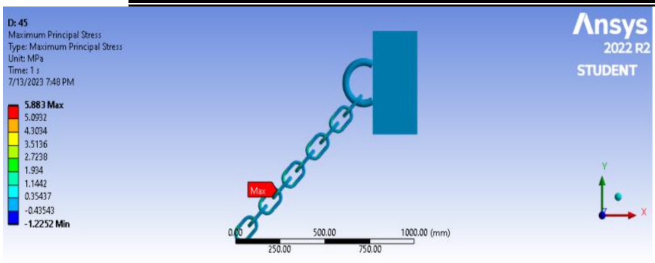


Figure 12. Simulation result at 45 degrees

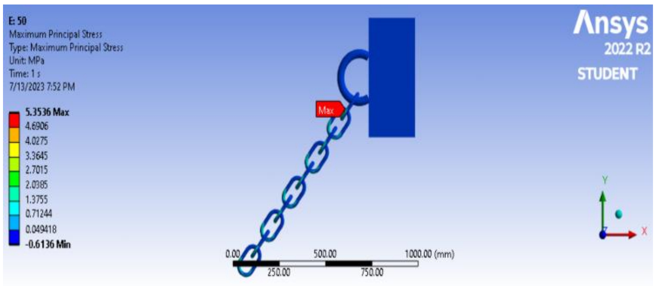


Figure 13. Simulation result at 50 degrees

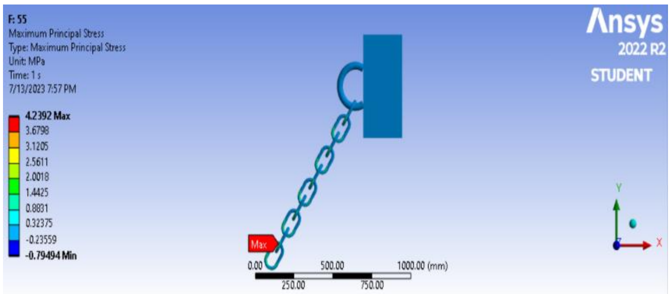


Figure 14. Simulation result at 55 degrees

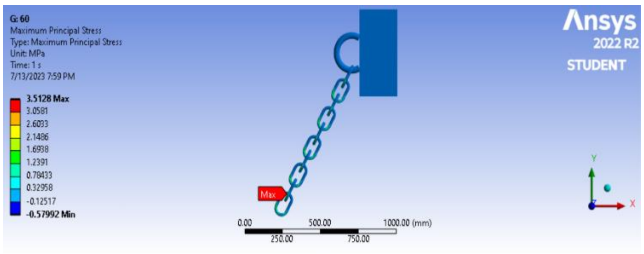


Figure 15. Simulation result at 60 degrees

The simulation results for anchor chain angles of 30°, 35°, 40°, 45°, 50°, 55°, and 60° are visually presented in Figures 9 through 15, respectively, illustrating the stress contours and distribution across the chain links for each angle. These figures highlight areas of stress concentration, typically at the points of contact and curvature within the links, consistent with expected structural behavior under tensile loading.

The detailed numerical results for the maximum stress values observed on the anchor chain at each angle are as follows: 6.668 MPa at 30 degrees (Figure 9), 6.9943 MPa at 35 degrees (Figure 10), 5.0428 MPa at 40 degrees (Figure 11), 5.883 MPa at 45 degrees (Figure 12), 5.3536 MPa at 50 degrees (Figure 13), 4.2392 MPa at 55 degrees (Figure 14), and 3.5128 MPa at 60 degrees (Figure 15).

Among these, the highest stress recorded was 6.9943 MPa at an angle of 35 degrees. This peak stress at 35 degrees is likely attributable to the specific orientation of the chain links at this angle, which may lead to an optimal alignment of the applied force with the link's geometry, thereby maximizing stress concentration at critical points such as the inner radius of the link.

Crucially, these findings indicate that the anchor chain structure remains in a safe operational condition under the simulated static loads. The maximum stress experienced by the chain (6.9943 MPa) is significantly below the material's Ultimate Tensile Strength (UTS) of 515 MPa. This large difference suggests a substantial safety margin for the static loading conditions analyzed.

## CONCLUSION

The analysis of the anchor chain under various force angles confirms that its structural integrity remains well within safe operational limits. Simulation results consistently demonstrate that, for all tested angles, the maximum stress experienced by the chain is substantially lower than the material's Ultimate Tensile Strength (UTS). This outcome indicates that the anchor chain can reliably withstand the applied static loads without risk of failure. Additionally, the findings highlight a specific angle at which stress concentration is highest, primarily due to the geometry and orientation of the chain links. Overall, Finite Element Analysis (FEA) has proven to be an effective and reliable method for assessing the structural safety and performance of anchor chains in maritime applications. Recommendations for future research:

- Dynamic Loading Analysis: Future research should incorporate dynamic loading conditions, including the effects of waves, currents, and vessel motion, to more accurately reflect real-world operational scenarios.
- Fatigue and Corrosion Evaluation: It is recommended to assess the long-term performance of anchor chains by analyzing fatigue life and the impact of marine corrosion, as these factors significantly influence structural reliability in harsh marine environments.

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