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Strength Analysis of 230 Feet Coal Barge Deck Using Finite Element Method

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ABSTRACT

Coal barges are one of the vital modes of transportation in the coal mining industry to transport large loads by sea or river. The durability of the deck structure is a crucial aspect in ensuring operational safety and efficiency. This study analyzes the strength of a 230-feet coal barge deck using the Finite Element Method (FEM) with variations in plate thickness. The analysis was carried out by modeling the deck structure in Autodesk Autocad software and simulating it in Ansys Workbench software. The purpose of this study is to evaluate the distribution of maximum stress and safety factor at maximum loading conditions. The analysis results show that the deck cargo model A with a plate thickness of 10 mm had a maximum stress of 175.65 MPa and a safety factor value of 1.22. Meanwhile, the deck cargo model B with a plate thickness according to the Ultrasonic Test results had a maximum stress of 181.71 MPa and a safety factor value of 1.18. The maximum stress and safety factor values of both models remain within the allowable stress limits and comply with the safety factor standards set by BKI (Biro Klasifikasi Indonesia) in Volume II, Chapter 5.

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INTRODUCTION

Coal is a carbonaceous organic sediment formed from plant remains through complex geochemical and biochemical processes over millions of years (Kementrian ESDM, 2025). In maritime transport, coal is commonly carried using barges, where the cargo is placed on the deck and confined laterally by sideboards to prevent spillage and ensure stability. The deck, therefore, serves as a structurally vital component in coal transportation, functioning as the primary load-bearing platform that accommodates and distributes the cargo weight throughout the vessel's structure.

According to (Biro Klasifikasi Indonesia, 2022) on coal barge vessels, the deck functions as the primary support area for coal cargo, which carries substantial loads, and therefore must be structurally reinforced and carefully evaluated. In the design of a coal barge deck structure, it is essential to ensure that the initial design possesses sufficient strength to withstand the cargo loads during vessel operation. As the main component supporting the coal cargo and distributing its weight, the deck must be thoroughly analyzed to determine the maximum stress generated by coal pressure. The accuracy of maximum stress calculation at the initial design stage is critical in determining both the structural feasibility of the deck and the overall safety of the vessel.

The strength and feasibility of the deck structure significantly affect the operational performance of the vessel, and one of the key parameters of deck feasibility is the thickness of the plate used. According to BKI Vol. II Sec. 2 (2022), the allowable tolerance for plate thickness reduction is 20% of the original thickness; if the reduction exceeds 20%, a replating process must be carried out (Biro Klasifikasi Indonesia, 2022). However, if a plate is already below the required thickness standard and no replating process is performed, it poses a serious hazard, as the deck may experience sudden and catastrophic structural failure. In cases where the plate thickness no longer meets the standard and replating is not conducted, a strength analysis of the existing deck structure must be performed to determine whether the deck is still capable of withstanding the coal pressure during barge operations.

To comprehensively assess feasibility, it is not sufficient to only determine the maximum stress value; it is also necessary to calculate the safety factor. The safety factor is a parameter that indicates the capability of an engineering material to withstand external loads, whether compressive or tensile (Arswendo & Arifin, 2011). In this study, the safety factor serves as a primary indicator to determine whether the deck of the coal barge is capable of resisting the pressure exerted by the coal cargo during operation without experiencing damage or structural failure. The results of the safety factor analysis provide an objective assessment of the structural strength limits of the deck, both at the initial design stage and after the Ultrasonic Test.

Based on these considerations, the author intends to analyze the deck strength with respect to the influence of plate thickness in both the initial design condition and during the docking process, using the Finite Element Method (FEM) with the assistance of ANSYS Workbench software. This analysis aims to determine the maximum deck stress in the initial design, the maximum deck stress during docking, and the corresponding safety factor.

METHOD

The study followed a methodology presented

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in Figure 1. In this section, strength analysis is carried out on the cargo deck with different plate thickness variations. There are two models that will be analyzed, with details of model A being the cargo deck model with the original plate thickness of the ship when it was first built, and model B is the cargo deck model with the plate thickness based on the results of the ultrasonic test that has been carried out.

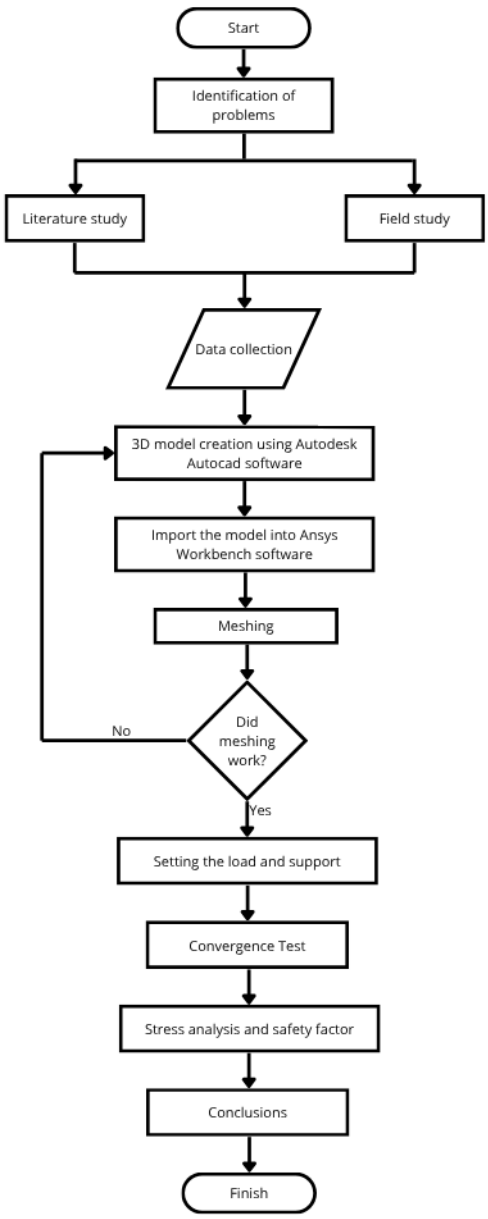

Figure 1. The methodology of research

Finite Element Method

The Finite Element Method (FEM) is a numerical approach used to solve various problems in the fields of engineering and mathematical physics. In its application, this method requires a discretization process to transform differential equations into a set of algebraic equations. This process involves the formulation of the stiffness matrix, the force vector, and the displacement vector, which are initially unknown. The principle of discretization in this method is to model a structure or structural component as an assembly of smaller finite elements. (Logan, 2005).

In this study, the Von Mises stress of both models will be analyzed. The Von Mises stress is a formulation derived from the Von Mises yield criterion, which is used to predict the material response under specific loading conditions. (Avianto, et al., 2013).

Convergence

According to (Khairunnisa, 2022) in the use of finite element method software, the more elements used, the more accurate the analysis results obtained. However, the increase in the number of elements is accompanied by an increasing time required for the analysis process. If the computer used is inadequate, this can cause errors or even cause the computer. Therefore, it is advisable to determine the number of elements that provide acceptable accuracy values. This process is carried out through the meshing step and testing the model several times with different meshing sizes, then comparing the results of the analysis. If there is a significant difference between the results obtained, the results can be considered convergent. According to Cook, a problem model is considered convergent if the difference in the results of the convergence test is approximately 5% (Cook, 1995).

Load Calculation

In this section, the coal load was simulated in a mountainous position as illustrated in Figures 2 and 3. Calculation of coal pressure on deck cargo can be done by multiplying coal density, Earth's gravitational acceleration, and load height. Then the calculation results can be seen in Table 1.

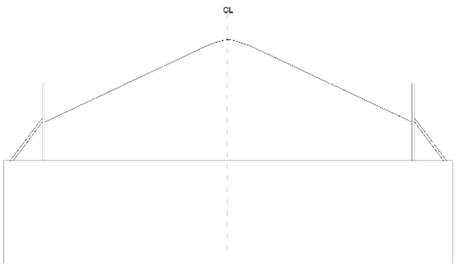

Figure 2. Simulation of a mountainous load condition

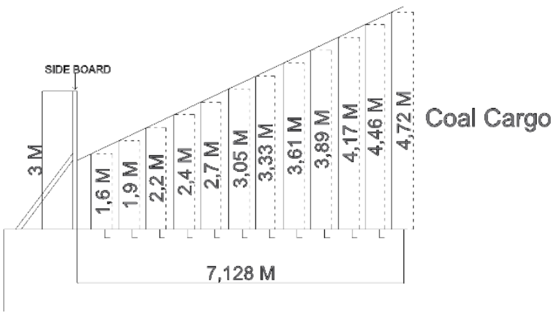

Figure 3. Coal height division for load calculation

Table 1. Coal pressure calculation results

Coal Height (m)	Pressure (Mpa)
1.64	0.013
1.92	0.016
2.20	0.018
2.49	0.020
2.76	0.023
3.05	0.025
3.33	0.027
3.61	0.030
3.89	0.032
4.17	0.035
4.46	0.037
4.72	0.039

RESULTS AND DISCUSSION

In this study, the coal barge that will be analyzed has principal dimensions that can be seen in Table 2.

Table 2. Principal dimension of the coal barge

Principal Dimension	Values (m)
Length over All (LoA)	67,30
Breadth (B)	21,34
Height (H)	4,27

In Table 3, it can be seen that the data on the material size used in the initial construction of the cargo deck. In Figure 5, it can be seen that it is a 3D model of the existing design, and in Figure 6, it can be seen that it is a 3D model of the ultrasonic test results with different deck plate thicknesses.

Table 3. Initial construction

Construction Section	Profile (mm)
Deck Plate	6000 x 1830 x 10
Deck Longitudinal	125 x 80 x 8
Web Frame	480 x 110 x 8

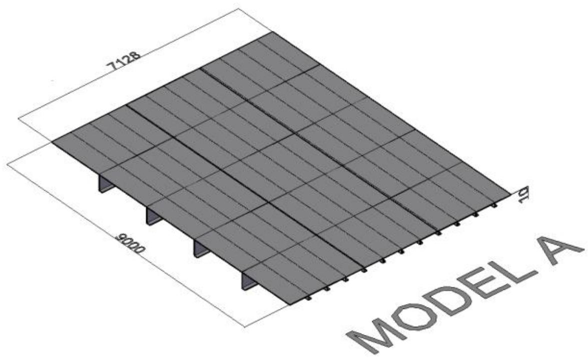

Figure 5. 3D model of the initial construction

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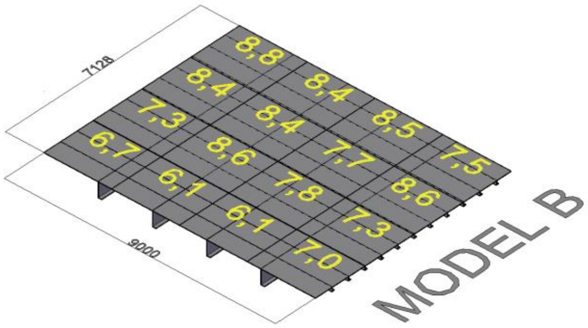

Figure 6. 3D model of the ultrasonic test results

Simulation in Finite Element Software

In the finite element method simulation, there are several stages that must be done: first, input the material data used, select the meshing method and size, provide pressure and gravity, provide fixed support to the model, and select the appropriate solution. After the simulation is carried out, the results of the stress of the two models will be converged; the results of one of the model simulations can be seen in Figure 7.

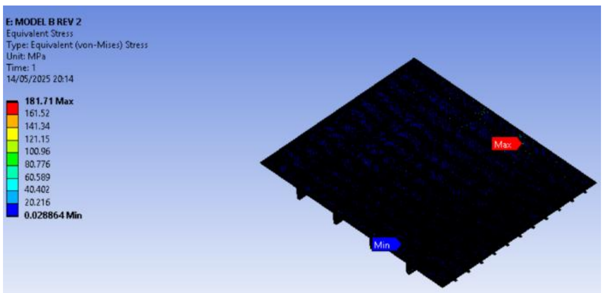

Figure 7. Stress simulation results in finite element software

After the simulation is carried out on both models, the stress results will be converged. Table 4 is the convergence on model A, and Table 5 is the convergence on model B.

Table 4. Convergence on model A

Size Mesh (mm)	Element Number	Von Mises Stress (MPa)	Difference stress (%)
100	95944	252.56	
95	130711	170.81	47.86
90	133232	174.31	3.66
85	144201	169.77	4.44
80	146769	171.38	0.93
75	152866	173.85	1.42
70	175426	175.65	1.47

Table 5. Convergence on model B

Size Mesh (mm)	Element Number	Von Mises Stress (MPa)	Difference stress (%)
100	112309	248.43	
95	125796	173.12	43.5
90	129107	170.09	1.78
85	142975	168.05	1.21
80	166686	174.35	4.32
75	176486	178.92	1.82
70	208849	181.71	1.53

Based on the convergence table above from both models, a meshing size convergence graph is made, compared to the stress results in both models.

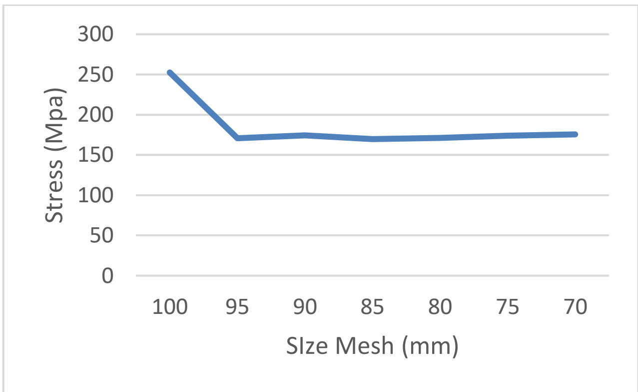

Figure 8. Convergence graph of model A

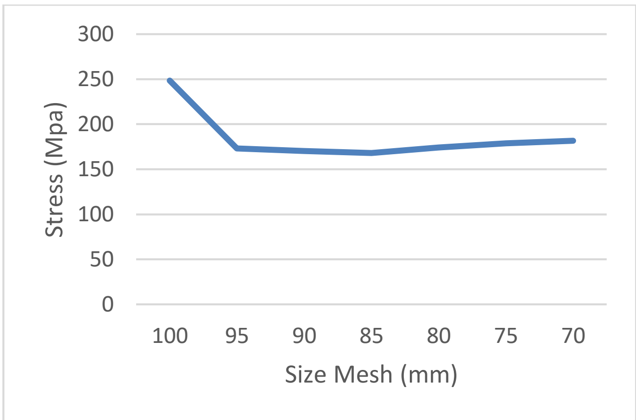

Figure 9. Convergence graph of model B

Stress Analysis

According to BKI Vol II Chapter 5 Section D.1.2. The magnitude of stress that occurs in the ship structure must be below the permissible stress. The allowable stress of a material can be calculated using the following equation. In this equation, *ReH* is the tensile yield strength of the used material (N/mm^2).

$$k = \frac{235}{ReH} \tag{1}$$

After the allowable stress of the used material is known and the highest stress of the two models is known, the next step is to carry out an allowable stress analysis. The stress considered for analysis is the highest stress value obtained from all simulation runs. In Model A, the maximum stress was taken at a mesh size of 70 mm, and in Model B, the maximum stress was also taken at a mesh size of 70 mm. The results of which can be seen in Table 6.

Table 6. Stress analysis results

Model	Von Mises Stress (MPa)	Allowable Stress	Status
A	175.65	215.9	Acceptable
B	181.71	215.9	Acceptable

Based on the analysis results, it is observed that model A, with a thicker plate compared to model B, can withstand the coal cargo pressure more effectively. This is evidenced by the fact that the maximum stress occurring in model A is lower than that in model B. This finding confirms that plate thickness has a significant influence on the structural strength of the coal barge deck.

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Safety Factor Analysis

The next step is to analyze the safety factor on the two models that have been tested. According to (Biro Klasifikasi Indonesia, 2022) Rules For Hull Sec.. 3. F.1 The safety factor value is ≥1.1. The safety factor value can be obtained through the equation.

$$SF = \frac{\sigma_{\text{allowable}}}{\sigma_{maks}} \tag{2}$$

The results of the safety factor analysis can be seen in Table 7.

Table 7. Safety factor results

Model	Safety factor	Standard	Status
A	1.22	1.1	Acceptable
B	1.18	1.1	Acceptable

CONCLUSION

Strength analysis in this study was performed by simulating a mountainous coal loading condition using the Finite Element Method (FEM), with a mesh size of 70 mm applied to both Model A and Model B. The results indicated that Model A, with a plate thickness of 10 mm, experienced a maximum stress of 175.65 MPa and achieved a safety factor of 1.22. Meanwhile, Model B, with a plate thickness determined from Ultrasonic Test measurements, recorded a maximum stress of 181.71 MPa and a safety factor of 1.18. These findings confirm that the maximum stress and safety factor values for both models remain within the allowable material stress limits and comply with the safety factor requirements established by BKI standards.

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