Analysis of Static Load Variation on the Structural Strength of the Polbeng 2 Engine Foundation Using the Finite Element Method

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Abstract

The engine foundation plays a critical role in maintaining the alignment, stability, and operational performance of a vessel's propulsion system. The Polbeng 2 training vessel underwent a main engine replacement from 71 HP to 15.78 HP, resulting in changes to the structural load transmitted to the foundation. This study aims to analyze the effect of static load variation on the strength and deformation of the Polbeng 2 engine foundation using the Finite Element Method (FEM). The 3D foundation model, initially designed with fiberglass material, was developed in Rhinoceros software and analyzed using ANSYS Student with static structural simulation. Two loading scenarios were evaluated: the initial engine load of 5560 N and the reduced load of 1815 N. Simulation results show a decrease in maximum Von Mises stress from 0.04 MPa to 0.016 MPa following the load reduction, accompanied by a proportional reduction in deformation. These results indicate that the modified engine foundation remains structurally safe under the new load conditions, demonstrating adequate strength and stiffness performance. This study highlights the importance of FEM-based assessment in ensuring design reliability during machinery replacement on training and operational vessels.

Keywords: Engine Foundation, Static Load, FEM, Stress Analysis, Ship Structure

1. INTRODUCTION

The Polbeng 2 training vessel, developed by the Department of Naval Architecture at Politeknik Negeri Bengkalis, was designed to support academic instruction and research activities. As a multifunctional platform, Polbeng 2 has been successfully integrated into campus operations as both a teaching facility and an educational transport medium. Its implementation represents a significant milestone in vocational engineering education, enabling the direct application of theoretical shipbuilding knowledge into real maritime practice.

The main engine constitutes a critical component of the propulsion system, responsible for the vessel's mobility and overall operational performance. To ensure proper placement and stability, the engine must be supported by a robust foundation within the engine room. This foundation carries loads generated by the engine weight, propeller thrust, and continuous vibration from engine operation (Grubišić, 2007). Functioning as a primary structural support and interface with the hull, the engine foundation must withstand constant operational loads. These loads are categorised as static, resulting from engine mass, auxiliary equipment, and fastening bolt forces. Insufficient foundation strength may lead to structural deformation, shaft misalignment, and subsequently, failure of the propulsion transmission system, potentially compromising vessel performance and operational safety (Imron, 2014).

Although Polbeng 2 was constructed in 2023, a decline in engine performance was observed after two years of service. Symptoms included unexpected engine shutdowns, unstable thrust, and severe mechanical failures. These issues disrupted educational activities and posed operational safety concerns. Consequently, the maintenance team elected to replace the main engine.

The engine replacement—from a 71 HP unit to a 15.78 HP unit—necessitated modifications to the engine foundation due to changes in load magnitude, vibration characteristics, and mounting bolt positions. Accordingly, this study aims to analyse the structural strength of the modified engine foundation using the Finite Element Method (FEM). Through this numerical approach, the distribution of stress and deformation under static loading conditions can be accurately evaluated, thereby determining the structural safety factor of the new foundation configuration.

2. REVIEW OF LITERATURE

a. Ship Engine Foundation

The engine foundation of a ship is a critical structural component responsible for safely and effectively transmitting the loads and vibrations generated by the main engine to the ship's hull. It is designed to withstand dynamic forces, torsional loads, and static stresses that arise during engine operation. In naval engineering practice, the foundation must satisfy strength, stiffness, and deformation-resistance requirements to ensure propulsion system reliability and prevent shaft misalignment and structural damage. As stated in the literature, *"the engine foundation serves as the primary supporting structure that transfers engine loads to the ship's framework with sufficient rigidity and durability to minimize vibration and displacement"* (SNAME, 2018).

International classification standards, including those issued by IMO and ABS, provide specific design criteria for engine foundations related to loading conditions, material selection, and vibration-transmission systems. The use of chocks and resin mounting systems is common to ensure alignment accuracy and installation stability. According to industry guidelines, *"engine foundation design must consider load distribution, vibration isolation, and joint integrity between the engine and hull structure to prevent resonance and material fatigue"* (ABS Rules for Marine Vessels, 2020). Therefore, evaluating the structural performance of engine foundations is essential to ensure operational safety and reliability of the vessel.

b. Loads

The loading acting on a ship's main engine is a combination of static, dynamic, and torsional forces that occur during propulsion system operation. Static loads originate from the mass of the engine and its supporting components, whereas dynamic loads arise from inertial forces generated by piston motion, crankshaft rotation, and fluctuating combustion pressure within the cylinders. These forces produce vibrations and varying load magnitudes that must be effectively transmitted through the engine foundation to the ship's structural framework. According to fundamental structural mechanics principles, *"engine loads consist of compressive, tensile, shear, and bending forces that act simultaneously during operation"* requiring that the foundation and its mounting connections be engineered to safely accommodate and distribute such loads (SNAME, 2018).

c. Stress

Stress is an internal force that acts on an infinitesimally small area of a section and consists of various magnitudes and directions of forces. The intensity of the force acting on an object varies from one point to another. The intensity of the force that is perpendicular to the object is called normal stress.

1) Compressive Stress

If the normal force acts exactly at the centroid of the cross-section, then it is said that the normal force acts concentrically (Dwi, 2021).

$$\sigma = \frac{\mathrm{N}}{\mathrm{A}} = \left(\frac{\mathrm{N}}{\mathrm{mm}^2}\right) \quad (1)$$

Where :
σ = Compressive Stress (N/mm²)
N = Compressive Force (N)
A = Cross-sectional Area (mm²)

2) Von-Mises Stress
Analisa menggunakan perangkat lunak elemen hingga memiliki kelebihan yaitu dapat menghasilkan nilai tegangan Von-mises atau tegangan equivalen, yaitu jenis tegangan yang mengakibatkan kegagalan pada struktur material yang dirumuskan oleh Von-mises. Untuk penentuan tegangan von-mises, terlebih dahulu menghitung tegangan utama yang bekerja pada struktur, setelah itu maka tegangan von-mises bisa dituntukan dengan persamaan, Fajar (2017).

$$\sigma = \{[\sigma 1 - \sigma 2]2 + [\sigma 2 + \sigma 3]2 + [\sigma 3 - \sigma 1]2\}1/2 \quad (2)$$

d. Deformation

Total deformation describes the magnitude of displacement of a structural element from its initial position due to loading. Deformation includes displacement in both translational and rotational directions, indicating the relative stiffness of a structure against the applied forces. Excessive deformation can cause misalignment of machine components and disturbances in the power transmission system. Deformation (δ) can be determined by:

$$\delta = \frac{P \times L}{A \times E} \quad (3)$$

Where :
E = Modulus of elasticity (N/mm²)
P = Applied force (N)
A = Cross-sectional area (mm²)
L = Initial length (mm)

e. The Finite Element Method

The Finite Element Method (FEM) is a numerical technique widely applied to solve complex engineering problems, particularly those related to structural behavior, vibration analysis, heat transfer, and fluid mechanics. The fundamental concept of FEM involves subdividing a structure or computational domain into numerous smaller interconnected elements through nodal points. Each element is assumed to exhibit defined mechanical characteristics, allowing the collective response to accurately represent the structural behavior of the entire system. As stated by Logan (2017), FEM facilitates the transformation of continuous systems into discrete models, enabling precise calculation of stress, strain, and deformation based on equilibrium principles and material constitutive laws.

Furthermore, FEM provides greater flexibility compared to traditional analytical approaches, allowing variations in geometry, loading conditions, and material properties to be examined comprehensively. In the maritime engineering field, FEM plays a crucial role in evaluating structural components such as engine foundations, hull frameworks, and propulsion elements to predict potential failures caused by dynamic loading and thermal stresses. Zienkiewicz et al. (2013) emphasize that FEM achieves high reliability in structural simulations through mathematical formulations based on the principle of minimum potential energy and the Galerkin method. Therefore, in this study, FEM is employed as the primary analytical approach to assess the mechanical response of the ship's engine foundation under static and dynamic loading conditions.

3. METHOD

This study employs a numerical approach using the Finite Element Method (FEM) to evaluate the structural strength of the ship's engine foundation. The research procedure consists of data acquisition, geometric modeling, meshing, application of boundary conditions and loading, numerical simulation, and result evaluation. The input data include the engine room foundation dimensions, commonly used ship structural material properties, and the main engine weight as the static load.

The geometric model of the engine foundation was developed using 3D CAD software and subsequently exported in IGES format. The model was then imported into FEM analysis software for meshing, where the element size was refined based on convergence criteria to ensure minimal variation in stress values with mesh refinement. Boundary conditions were applied by fixing the regions of the foundation connected to the ship structure, while the remaining surfaces were left unconstrained. Numerical simulation was performed using Ansys Student to obtain Von Mises stress distribution and total deformation results. The simulation outputs were compared with material strength limits to determine the structural safety factor. The foundation is considered structurally safe when the maximum stress does not exceed the allowable material stress and the deformation remains within acceptable design limits.

4. RESULT & DISCUSSION

a. 3D Modeling

To perform the FEM calculations using the Ansys Student version, the Polbeng 2 engine foundation—initially available only in a 2D form and constructed from fiberglass material—first needed to be converted into a 3D model. For this purpose, Rhinoceros software was selected to develop the 3D geometry of the foundation. Rhinoceros was chosen due to its user-friendly interface, ease of operation, and compatibility with various engineering platforms, including Ansys Student, allowing seamless export of the model for further numerical analysis.

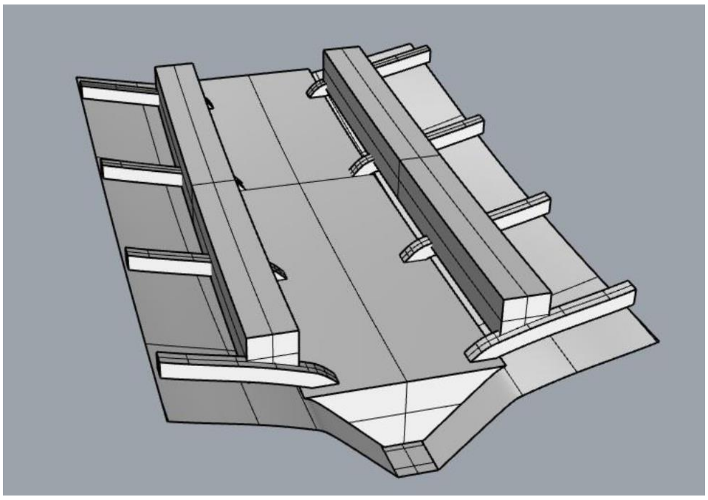


Fig. 1. 3D Model of the Polbeng 2 Vessel Foundation

b. Ansys Modelling

After the Polbeng 2 engine foundation was successfully converted into a 3D model as shown in Figure 2, the geometry was prepared for FEM analysis in Ansys. The Rhinoceros model was exported in STEP (.stp) format to minimize compatibility issues and reduce potential errors during the simulation process. Once the export was completed, the file was imported into Ansys through the *Import Geometry* option. Prior to running the analysis, the appropriate analysis type was selected; in this case, a *Static Structural* module was used for FEM evaluation. It is essential to ensure that the imported geometry is recognized as a solid model to enable accurate meshing and structural assessment within the software environment.

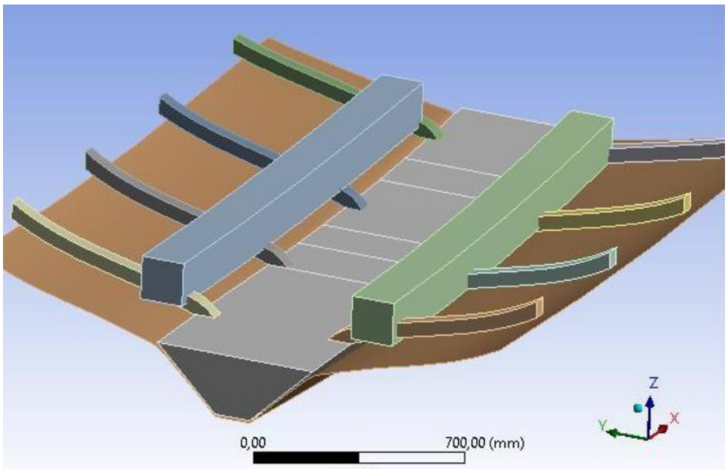
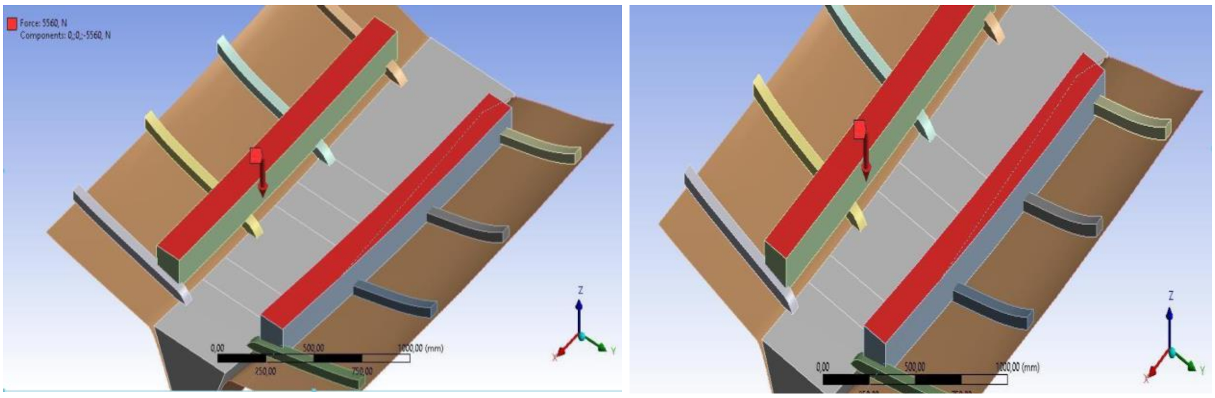


Fig. 2. Ansys Model of the Polbeng 2 Vessel Foundation

c. Load Input

The loading applied in this study was limited to static conditions, meaning the engine foundation was analyzed in a non-operating state without dynamic forces. Static loading refers to a constant and non-variable force acting on the structure. The load was applied to both sides of the engine foundation to represent the weight distribution of the main engine. Two loading scenarios were considered, as illustrated in the figure below:

1) Initial condition with a load of 5560 N
2) Modified condition with a reduced main engine load of 1815 N



(a) (b)

Fig. 3. Load Distribution (a = 5560 N) (b = 1815 N)

d. Stress Analysis

The simulation results yielded the maximum stress values and total deformation of the engine foundation structure. The numerical outcomes obtained from the FEM analysis are summarized in Table 1 below.

Tabel 1. Maximum Stress Value

Model	Max Stress (Mpa)	Min Stress (Mpa)
Initial Condition	4,00E-02 (0,04 Mpa	0
Change in Load	1,000E-02 (0,0016 Mpa	0

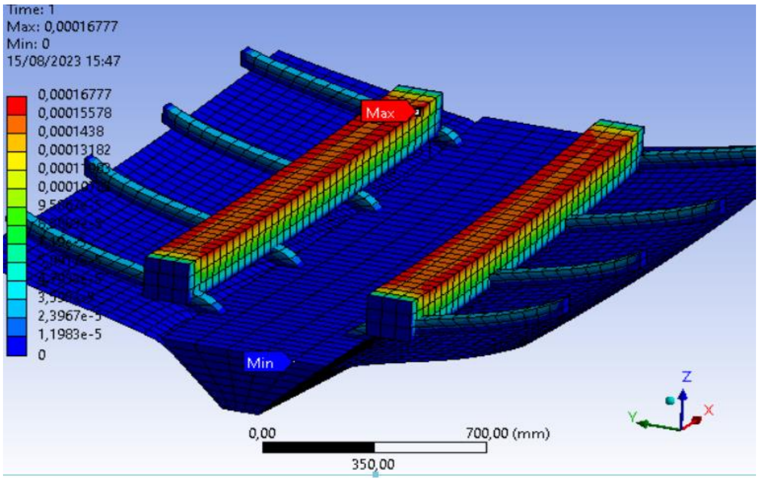


Fig. 4. Ansys Simulation Results

The findings indicate that model (a) experienced a peak stress of 0.04 MPa, while model (b) recorded a significantly lower maximum stress of 0.016 MPa, reflecting a reduction consistent with the change in applied load.

5. CONCLUSION

The results of the finite element analysis conducted on the Polbeng 2 vessel's engine foundation demonstrate a significant decrease in structural stress following the reduction of engine load. The maximum stress value dropped from 0.04 MPa to 0.016 MPa, indicating a substantial reduction that is directly proportional to the decrease in applied static load. This finding confirms that the engine foundation experiences lower mechanical demands under the new engine configuration, and the structure remains safely within material strength limits. The improved stress condition suggests a lower risk of structural deformation and fatigue over the vessel's operational life.

These results validate the application of the Finite Element Method (FEM) as a reliable and effective tool for evaluating the structural behavior of marine components under varying loading conditions. The analysis highlights the importance of assessing foundation performance when engine modifications or replacements are performed on vessels. Overall, the updated engine configuration contributes to enhanced structural safety and durability of the engine foundation on Polbeng 2, supporting safer operation and extended service life for the vessel's structural systems.

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