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DESIGN OF THE MAIN ENGINE FOUNDATION OF SHIP X TO SUPPORT MAIN ENGINE REPOWERING

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ABSTRACT

Ship "X" is one of the motor ships built in 1974 and is of the passenger type. Repowering is planned because the current speed is deemed insufficient to meet the expected operational targets. The ship uses the previous main engine with a capacity of 4 x 1340 HP to 2 x 2600 HP. An important part of the main engine is the foundation located at the bottom, because the foundation is attached to the main engine with a large power, the foundation must effectively ensure the safety of the hull structure to withstand a wide variety of forces that can be provided by loads on the foundation. The engine foundation must be able to withstand the load on it without causing shear stress, as if the engine has become an integral part of the ship itself. Given that this will be done, a new main engine foundation design process will be made. There are two types of materials simulated, namely bki grade A and B standard steel, with two loads during operation, namely a fixed load of 29,577.15 N and a total load of 165,128.41 N. In carrying out the research, modeling and simulation were carried out with Autodesk Inventor software. So, this research produces the most efficient material, namely bki grade A steel, because it has a greater yield strength and tensile strength. The material has simulation results with minimal and maximum difference values in %, Stress XY 0.56%, Stress Z 0, 11%, Stress YY 0.11%, Stress stress and strain of Von Mises Stress 0.05%, 1st Principal Stress 0.18%, 3rd Principal Stress 0.18%, Stress XX 0.03YZ 0.02%, Stress ZZ 0.07, Equivalent Strain 0.44%, 1st Principal Strain 0.46%, 3rd Principal Strain 12.25%, Strain XX 0.02%, Strain XY 0.18%, Strain XZ 0.09, Strain YY 0.22%, Strain YZ 0.36%, Strain ZZ 0.09%.

Keywords: Design, foundation, main engine, load, repowering, strain, strength, stress

Introduction

Ships are used as a means of sea transportation for goods, people, and services delivered by ship [1]. Ship X is a motor ship built in 1974 and sails under the Indonesian flag. The ship is a Roll-on/Roll-off (Passenger Ro-Ro) type, functioning as a passenger ship with destinations from Garongkong Port, Barru, South Sulawesi, to Paciran Port, Lamongan.

East Java. The ship renovation plan includes changing the main engine (repowering) from the original main engine with a capacity of 4 x 1340 HP to a main engine of 2 x 2600 HP. Renovations are also being carried out on the ship's accommodation section located above the vehicle deck, including the addition of capsule rooms for passengers, the addition of passenger service areas such as a gym, karaoke, barbershop, cafeteria, massage room, and open area [2]. Therefore, the main use of Ro-Ro ships is as a means of transportation, including off-road vehicles such as cars and trucks, as well as land transportation [3].

Repowering is still frequently carried out, although it is not the primary engineering choice. The main reason for this is the demand for stable ship performance, which includes meeting service speeds, economical ship operations, and uninterrupted performance. This occurs while ship owners do not have sufficient funds to build new ships [4]. Engines with high power require double base construction and a strong engine foundation so that the forces generated by the engine during operation can be absorbed. The engine foundation must be able to withstand the superimposed loads without causing shear or crushing failure. The shear stress that occurs on perpendicular planes must have zero components [5]. In ship construction, the engine foundation is very important because it bears the load from the main engine, the force from the propeller, and the vibration from the main engine [6]

To ensure the safety of the ship's hull structure, the main engine foundation must be able to withstand various variations in force that can place loads on the foundation. The engine foundation helps keep the engine upright in its position as if it were part of the ship. The foundation must be able to withstand deformation due to loads within the permissible limits if the drive motor foundation and the surrounding base structure have sufficient rigidity [7]. The engine foundation must be installed with special care so that the engine shaft axis and the propeller shaft axis are always straight [8].

Based on the above description, there is a need for research on the design of the main engine foundation on ship X to support this repowering. As there is no such research yet, the author proposes the title "Design of the Main Engine Foundation of Ship X to Support Main Engine Repowering". This research uses simulation with Autodesk Inventor Professional 2021 software to analyze the strength of the main engine foundation with different material specifications. This research aims to determine the load received by the new main engine foundation for the repowering plan on passenger ships, calculate the strength of the foundation with several material specifications, and the stress caused by the main engine.

Methodology

The methodology used in this research is a design method using AutoCAD software to create the construction form of the main engine foundation of ship X to support the repowering of the main engine. The model will then be tested for strength using simulations with Autodesk Inventor Professional 2021 software with material variations to determine which material is suitable. After that, it will be validated using manual calculations in accordance with applicable guidelines and standards.

The simulation results with static analysis were produced by Autodesk Inventor. Static analysis uses the finite element method and aims to determine whether the frame design and materials used are safe. This determines the stress on materials and structures that experience static or dynamic loads or forces. This condition is achieved if the stress that occurs does not exceed the yield strength. If the stress exceeds the yield strength, it will not return to its original shape when subjected to static loads. The Von Mises criterion determines whether a combination of stresses will cause failure. Von Mises stress is also known as equivalent stress. Principal stress indicates the maximum and minimum normal stresses that occur in a material during complex loading conditions. Determining the principal stress can reveal the most severe stress concentration when the material is subjected to multi-directional stress, which is very important for preventing structural failure. A perpendicular plane has zero shear stress components on that plane.

Two types of principal stress will be discussed here: First Principal Stress and Third 3rdPrincipal Stress [5]. Meanwhile, strain is when an object changes in size due to a force or couple in equilibrium compared to its initial size. Strain, also known as the degree of deformation, is measured to determine the amount of deformation when mechanical stress occurs. This produces a measure of the force that occurs, such as load and stress. In addition, it is used to calculate the strength and safety value of a material or structural component that contains it, which affects the safety factor. The Safety Factor is used to assess the safety of a frame. The safety factor can be determined either at the most extreme elastic stress or at the yield stress of the material. The safety factor is used to evaluate a design with the least assessment. The material and frame design are considered safe if the minimum value produced by the material and frame is not more than one [5].

In conducting this research, data related to the issues discussed in this study are required. In collecting this data, the observation method was used, which is data collection carried out by directly observing an object using the five senses. The data obtained will be used as a reference in the process of working on this research. During the implementation of this research, data collection was carried out to complete this proposal, both from the internet and from previous studies. The data collected for this proposal includes ship data such as overall length (LOA), ship height (H), ship width (B), ship draft (T) as shown in Table 1, engine room dimensions, new main engine specifications, new main engine dimensions, marine gear specifications, plate dimensions, plate specifications, and plate composition as shown. The ship used as the object of research in this study is a Ro-Ro passenger ship, as shown in Table 1.

Table 1. Main ship data

No	Parameter	Symbol	Value
1	Total Length (m)	LOA	88,91
2	Length Perpendicular (m)	LPP	84,00
3	Waterline Length (m)	LWL	3,7
4	Maximum Width (m)	B	15,80
5	Height (m)	H	5,54
6	Water Depth (m)	T	3,70
7	Service Speed (knot)	Vs	15.25

Table 1 shows the main data of the ship that will be used for this study, namely, a passenger ship. The main ship data includes Length Over All (LOA), Length between Perpendicular (LPP), Length Water Line (LWL), Breadth (B), Height (H), Draft (T), Service Speed (Vs) [2].

Table 2. Engine room dimensions

No	Parameter	Value (m)
1	Length	23.4
2	Width	11.4
3	Height	5.54
4	Length for main engine	7.4

Table 2 shows the dimensions of the engine room that will be used for this study. The dimensions of the engine room are a key parameter in the construction of the main engine foundation because the dimensions of the main engine to be used are different from those of the previous main engine.

Table 3. New main engine

No	Parameter	Value
1	Brand	Yanmar 6EY26W
2	Type	4-stroke, Diesel
3	Piston Stroke (mm)	385
4	Piston Speed (m/s)	9.63
5	Number of Cylinders	In-line 6
6	Cylinder Bore (mm)	260
7	MEP (MPa)	1.92–2.50
8	Rated Output (PS)	2610
9	Rated Engine Speed (rpm)	750
10	Dry Weight (kg)	18500

Table 3 shows the specifications of the new main engine [9], which will be used to determine the forces that will be generated in designing the main engine foundation of the ship. These main gine specifications are used to calculate the forces that will be exerted and input into the software setup that will determine the engine undation model.

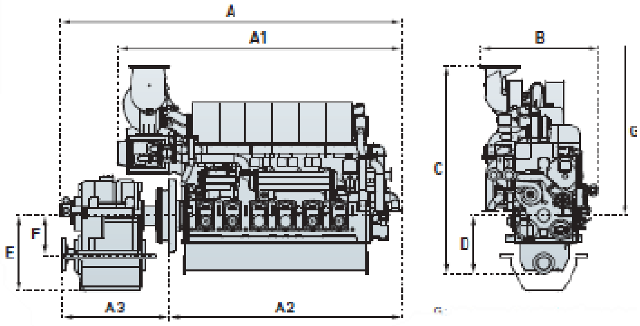

Figure 1. Maine engine dimensions

Table 4. Main engine dimensions value

No	Parameter	Value (mm)
1	A	5601
2	A1	4271
3	A2	3563
4	A3	2070
5	B	1804
6	C	3112
7	D	842
8	E	555
9	F	—
10	G	1900

Figure 1 and Table 4 show the dimensions of the new main engine [9] that will be used for this study. The dimensions of this new main engine are the main parameters for designing the engine foundation, starting from a two-dimensional design and developing it into a three-dimensional one.

Table 5. Marine gear specifications

No	Parameter	Value
1	Marine Gear Model	Yanmar YXH 2500C
2	Propeller Type	F.P.P.

3	Reduction Gear Ratio (Forward)	2.23, 2.58, 2.79, 3.03
4	Marine Gear Dry Weight (kg)	4800
5	Total Dry Weight with Marine Gear (kg)	23840

Table 5 shows the specifications of the marine gear [9] that will be used to complete this study. These marine gear specifications serve as supplementary data in this study.

Table 6 shows the dimensions of the plate that will be used for this study. These plate dimensions are used in the plate size for designing the machine foundation model. The specification is shown in Table 7. Table 8 shows the composition of the plate that will be used to complete this study. The composition of the plate affects the specifications of the plate that will be used.

Table 6. Plate dimensions

No	Parameter	Value
1	Thickness (mm)	4 – 25
2	Width (mm)	300 – 2000
3	Length (mm)	1250 – 12500
4	Weight (kg)	875 – 2625
5	Pallet Weight (Metric Ton)	6

Table 7. Plate specifications

No	Specification	Value
1	Grade	A
2	Yield Strength (MPa)	292 min.
3	Tensile Strength (MPa)	430
4	Elongation (%)	28 min.
5	Impact Energy (Joule)	Not specified

Table 8. Composition of plate content

No	Element / Content	Value (%)
1	Carbon (C)	0.1721
2	Silicon (Si)	0.195
3	Manganese (Mn)	0.520
4	Phosphorus (P)	0.108
5	Sulfur (S)	0.0087
6	Chromium (Cr)	0.014
7	Nickel (Ni)	0.007
8	Copper (Cu)	0.015
9	Molybdenum (Mo)	0.001
10	Vanadium (V)	-

a. Calculation of Load Received by the Foundation

The stage of calculating the load that will be received by the ship's main engine foundation using formulas and provisions by the Indonesian Classification Bureau (BKI). The calculation of the main engine foundation load is based on the weight of the main engine and the forces that will be generated when the engine is operating.

b. Main Engine Load

The main engine load is generated from the weight of the main engine, which is distributed evenly on the foundation and is also influenced by the torque/rotation of the engine with a vertical load reaction. This vertical load increases the engine load on one side and reduces the main engine load by the same value on the other side.

W mainengine = Weight x Gravity
= 3015 kg x 9.81 m/s^2
= 29577.15 N/m

c. Torsional Load on the Shaft

The shaft functions as a power transmitter from the engine to the propulsor. The power transmitted by the shaft is in the form of torsional moment. Several calculations must be performed to determine the torsional load on the shaft.

d. Main Engine Foundation Construction Calculations

The thickness of the construction is calculated in accordance with the Indonesian Classification Bureau, as in Table 8, Rules for Hull Volume II Edition 2009, Section 6. The depth of plate floors, the web thickness is not to be less than:

$T = h100+4,0$ s (mm)

Where:
h = floor plate depth according to section A.1.2.1.

Table 9. Engine bed thickness

No	Plate	Dimensions (thickness × width × length)
1	Krakatau Steel	35 × 325 × 4550

Plate floors shall be installed on each frame. The longitudinal girders of the engine seating are to be supported transversely by means of web frames or wing bulkheads. The scantlings of web frames are to be determined according to Section 9, A.6. Floor thickness according to B.6.2. The thickness of the longitudinal beams above the inner base in Table 9 shows the engine bed dimensions planned by the shipyard and must not be less than as Ref: BKI Th. 2019 Sec.B.6.2.

e. Designing the Main Machine Foundation Model

The 2-dimensional design process is the earliest process in the creation of the main engine foundation model. In this process, the dimensions used are those that have been calculated previously with the rules that must be met. The design that has been made consists of a top view in Figure 2, a side view in Figure 3, and a front view in Figure 4.

The initial step in forming the model geometry is to redraw the 2D design from AutoCAD 2018 software to Autodesk Inventor Professional 2021 software, then develop it into a part geometry model. After that, the developed parts are assembled or combined into a complete construction.

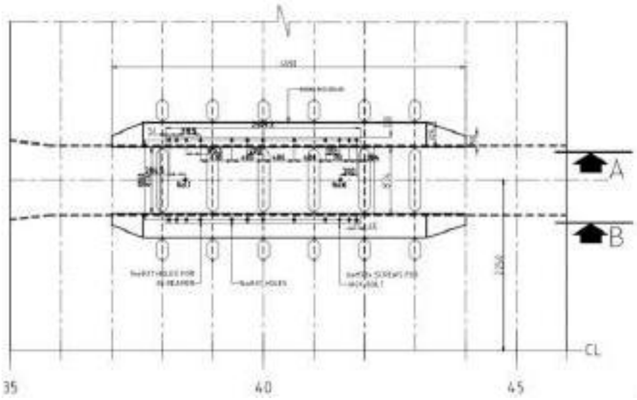

Figure 2. Top view of the main engine foundation

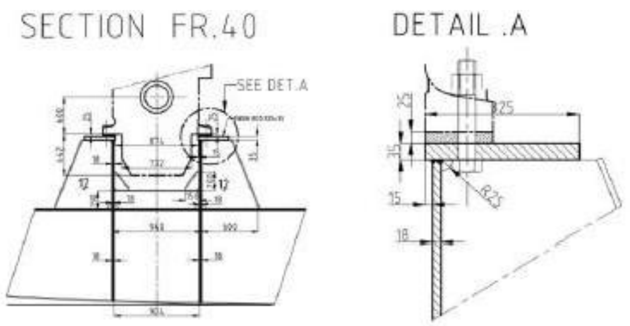

Figure 3. Front view of the main engine foundation

Figure 5 shows the stage of developing a 2- 2-dimensional sketch into a geometry model in the side view, front view, and top view, resulting in a construction part with a thickness varying between 10 mm and 35 mm using the extrude menu from the geometry results using Autodesk Inventor Professional.

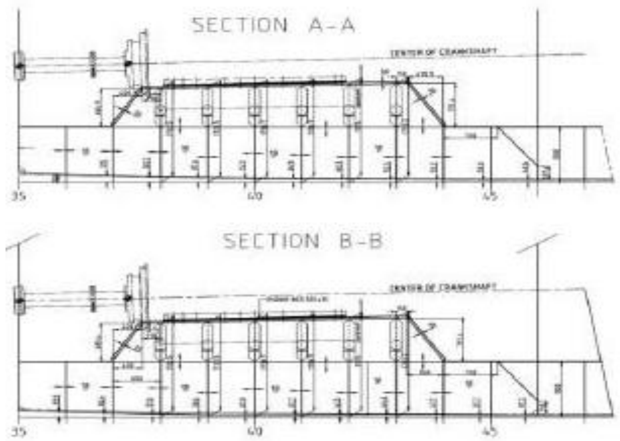

Figure 4. Side view of the main engine foundation

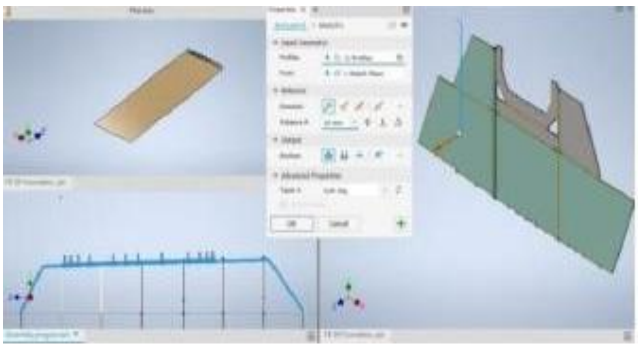

Figure 5. 3D modeling of the main engine foundation

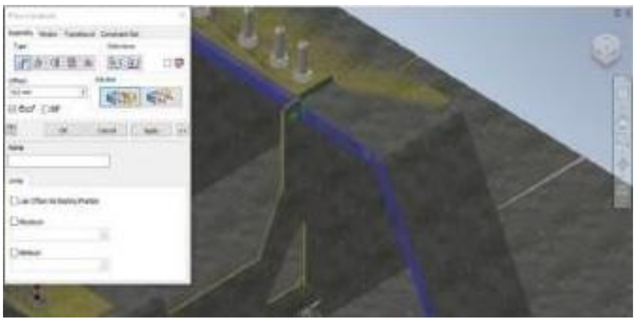

Figure 6. Assembly 3D part constraint

After the geometry is complete, the next step is to perform assembly geometry. The geometry to be tested must first be combined to form a construction with volume so that a simulation can be performed to determine the load that will be received and the strength of the foundation construction. Figure 6 shows the assembly stage with a 0.0 mm constraint mate and 0.0 mm flush from the assembly results using Autodesk Inventor Professional.

Figure 7 shows the meshing stage with a face size of 0.1 mm, which produced 568,881 elements and 304,159 nodes from the results of converting the mesh view using Autodesk Inventor Professional.

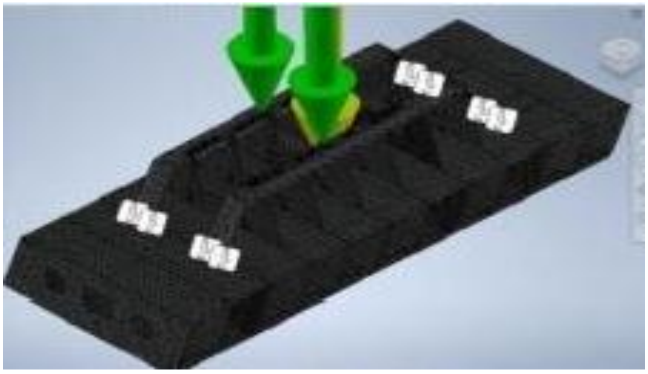

Figure 7. Mesh view display of the engine foundation

The setup process is the most important process because all parameters for the simulation are processed at this stage. There are many things that must be done to determine the boundary conditions in relation to a simulation. Here are some things that need to be set in the setup process, as shown in Table 10.

The following is the physical material setup in the main engine foundation model with varying material specifications. Figure 8 shows the physical material model with grade A steel with a yield strength of 282 MPa and a tensile strength of 441 MPa, and Figure 9 shows grade B with a yield strength of 235 MPa and a tensile strength of 400 MPa.

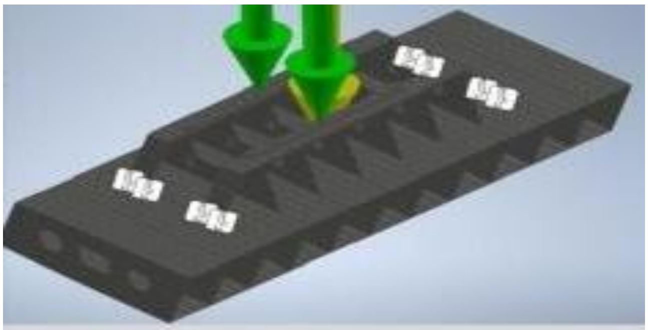

Figure 8. Physical material model of steel grade A

Table 10. Engine setup

No	Force / Stress	Value
1	Gravity	9.81 m/s^2
2	Force	29,577.15 N
3	Torsional Shaft Force	13,555,126.097 N

Result and Discussion

The simulation results from Autodesk Inventor Professional software on the steel grade A and B foundation models were used to determine the strength of the foundation (load, stress received by the foundation, and safety factor).

a. The Effect of Constant Loading on Stress and Strain

Analysis results of stress and strain on the main engine foundation material with variations in BKI steel grades A and B under a load of 29,577.15 N. To facilitate the analysis process, probe coordinates were assigned in the form of letters A, B, C, and D to determine the amount of stress at each point.

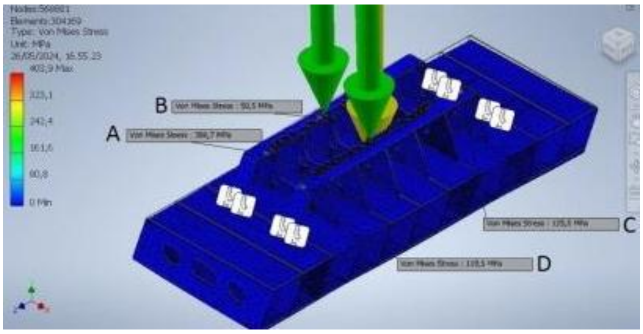

Figure 9. Von misses stress model A for constant loading

Table 11. Probe points for stress values in models A and B

Stress Type	A (MPa)	B (MPa)	C (MPa)	D (MPa)
Von Mises Stress	352.9	53.7	128.6	120
1st Principal Stress	406.6	-1.2	65.3	125.1
3rd Principal Stress	28.1	-57.8	-82.7	-6
Stress XX	115.9	-2.5	24.1	22.8
Stress XY	-88.4	-2.3	6.9	-7.1
Stress XZ	26.73	-2.4	-49.37	13.6
Stress YY	345.2	-7.2	-1.8	24.6
Stress YZ	-100.9	6.3	-45.4	-54.8
Stress ZZ	60.3	-57	-37.7	92.2

Table 11 shows the probe points (A, B, C, and D) of the four probes, indicating the main locations where stress occurs. The stress values are at the lower frame, the center of the engine bed, and the engine bed bend reinforcement of model A under constant loading.

Table 12 shows the probe points (A, B, C, and D) of the four probes, indicating the main locations of strain occurrence. The strain values are at the lower frame, the middle of the engine bed, and the engine bed bend reinforcement of model A under constant loading.

b. The Effect of Total Loading on Stress and Strain

The results of the stress and strain analysis on the main engine foundation material with variations in BKI grade A and B steel material under a load of 165,128.41 N. To simplify the analysis process, only the total load was compared because the results showed significant differences. Probe coordinates were labeled A, B, C, and D to determine the amount of stress at each point.

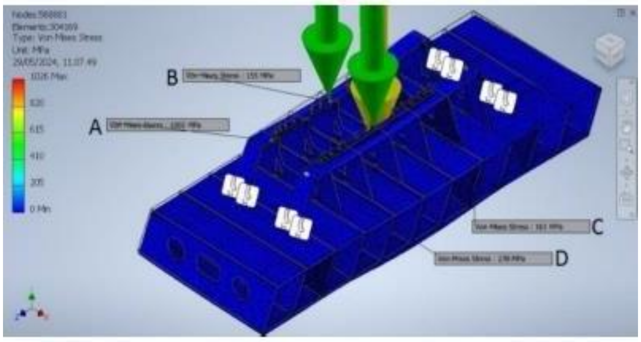

Figure 10. Von misses stress model A for total loading

Figure 10 shows an example of the Von Mises stress results on BKI grade A steel material with a load of 165,128.41 N. The green arrow indicates the direction of the load acting directly above the engine bed, and the yellow arrow indicates the assumed direction of gravity. The minimum von Mises stress is 0 MPa, and the maximum is 1026 MPa. The von Misses stress color indicator ranges from blue to red; the closer the color is to red, the higher the von Misses stress value. For the results of 1st Principal Stress, 3rd Principal Stress, Stress XX, Stress XY, Stress XZ, Stress YY, Stress YX, Stress ZZ, and equivalent strain values, 1st Principal Strain, 3rd Principal Strain, Strain XX, Strain XY, Strain XZ, Strain YY, Strain YZ, and Strain ZZ, with the difference will be presented in Table 11.

Table 13. Comparison of model A results for total loading

Results	Model A (Maximum)
Von Mises Stress	1026 MPa
1st Principal Stress	1109 MPa
3rd Principal Stress	195.1 MPa
Stress XX	343.5 MPa
Stress XY	232.7 MPa
Stress XZ	188.3 MPa
Stress YY	943.7 MPa
Stress YZ	432.6 MPa
Stress ZZ	427.7 MPa
Equivalent Strain	0.00450601 μl
1st Principal Strain	0.00506355 μl
3rd Principal Strain	0.0000426485 μl
Strain XX	0.00132967 μl
Strain XY	0.00149032 μl
Strain XZ	0.0019083 μl
Strain YY	0.00459041 μl
Strain YZ	0.00250916 μl
Strain ZZ	0.00150500 μl

The comparison data for model A in Table 13 shows that the simulation results for grade A bki plate material are in good agreement with the simulation results, showing significant results.

Table 14. Comparison of probe point A under constant loading

Results	Model A (Point A)
Von Mises Stress	962 MPa
1st Principal Stress	989 MPa
3rd Principal Stress	-77.6 MPa
Stress XX	198.8 MPa
Stress XY	-91.7 MPa
Stress XZ	44.2 MPa
Stress YY	904 MPa
Stress YZ	-265.9 MPa
Stress ZZ	-4.2 MPa
Equivalent Strain	0.004259 μl
1st Principal Strain	0.004910 μl
3rd Principal Strain	-0.001784 μl
Strain XX	-0.000266 μl
Strain XY	-0.000587 μl
Strain XZ	0.000283 μl
Strain YY	0.004248 μl
Strain YZ	-0.001427 μl
Strain ZZ	-0.001565 μl

The comparison data for probe point A in Table 14 shows that the simulation results in Autodesk Inventor Professional software are significant.

Table 15. Comparison of probe point B total load

Results	Model A (Point B)
Von Mises Stress	167 MPa

1st Principal Stress	0 MPa
3rd Principal Stress	-168.4 MPa
Stress XX	-3.9 MPa
Stress XY	-0.1 MPa
Stress XZ	1 MPa
Stress YY	-0.1 MPa
Stress YZ	5 MPa
Stress ZZ	-168.2 MPa
Equivalent Strain	0.000733 µl
1st Principal Strain	0.000345 µl
3rd Principal Strain	-0.000782 µl
Strain XX	0.000216 µl
Strain XY	-0.000001 µl
Strain XZ	0.000006 µl
Strain YY	0.000241 µl
Strain YZ	-0.000001 µl
Strain ZZ	-0.000836 µl

Table 16. Comparison of probe point C total load

Results	Model A (Point C)
Von Mises Stress	156 MPa
1st Principal Stress	167 MPa
3rd Principal Stress	2.7 MPa
Stress XX	47.4 MPa
Stress XY	-7.4 MPa
Stress XZ	-56.7 MPa
Stress YY	4.2 MPa
Stress YZ	5.4 MPa
Stress ZZ	139.9 MPa
Equivalent Strain	0.00064 µl
1st Principal Strain	0.000805 µl
3rd Principal Strain	-0.00026 µl
Strain XX	0.000035 µl
Strain XY	-0.000047 µl
Strain XZ	-0.000363 µl
Strain YY	-0.000241 µl
Strain YZ	-0.000030 µl
Strain ZZ	0.000628 µl

The comparison data for probe point B in Table 15 shows that the simulation results in Autodesk Inventor Professional software are significant. Moreover, the comparison data for probe point C in Table 16 shows that the simulation results in Autodesk Inventor Professional software are significant. Furthermore, the comparison data for probe point D in Table 17 shows that the simulation results in Autodesk Inventor Professional software are significant.

Table 17. Comparison of probe point D total load

Results	Model A (Point D)
Von Mises Stress	267 MPa
1st Principal Stress	277 MPa
3rd Principal Stress	-13.6 MPa
Stress XX	48.1 MPa
Stress XY	-13 MPa
Stress XZ	25.7 MPa
Stress YY	53.9 MPa
Stress YZ	-121.8 MPa
Stress ZZ	206.2 MPa
Equivalent Strain	0.001182 µl
1st Principal Strain	0.001375 µl
3rd Principal Strain	-0.000535 µl
Strain XX	-0.000124 µl
Strain XY	-0.000083 µl
Strain XZ	0.000165 µl
Strain YY	-0.000086 µl
Strain YZ	-0.000560 µl
Strain ZZ	0.000888 µl

c. Safety Factor Analysis

Safety factor analysis results for the main engine foundation material with variations in BKI grade A and B steel materials against the load received. To simplify the process, probe coordinates are given in the form of letters A, B, C, and D to determine the amount of stress at that point.

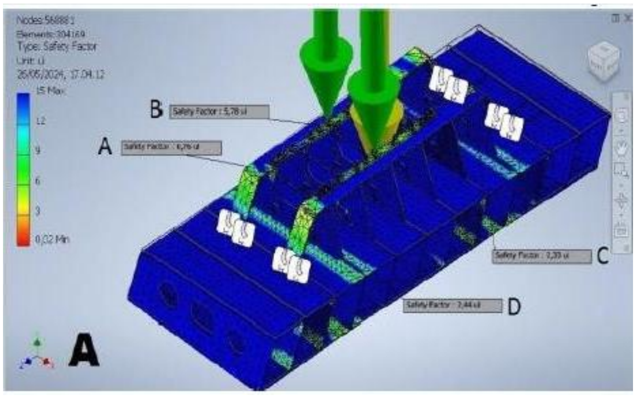

Figure 11. Safety factor A with constant loading

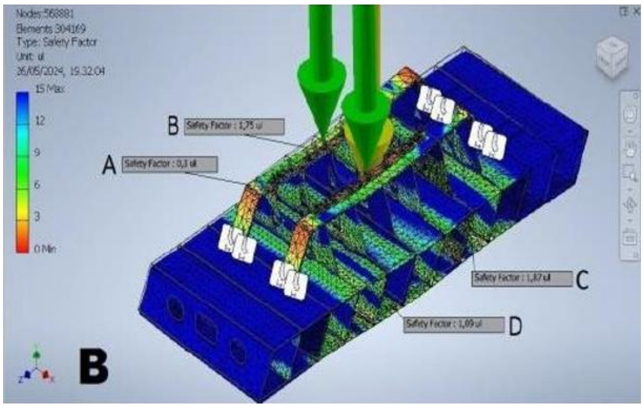

Figure 12. Safety factor A with total loading

Figures 11 and 12 show the safety factor around the main engine foundation with two variations of material model A, with fixed and total loading. The color representation starts from the bottom color, which is red, and the top color, which is blue. The higher the color, the greater the safety factor. Therefore, the bluer the color, the safer it is, and the redder the color, the more dangerous the safety factor of the material is.

The data on the safety factor of material model A in Table 18 shows that the simulation results in Autodesk Inventor Professional software have significant differences in each probe in the safety factor of the two models, namely, probe point A 30.43%, probe point B 15.89%, probe point C 30.43%, and probe point D 25.29%.

Table 18. Safety factor comparison

Results	**Model A**
Probe Point A (μl)	0.30
Probe Point B (μl)	1.75
Probe Point C (μl)	1.87
Probe Point D (μl)	1.09

Conclusion

For the construction of the main engine foundation for repowering planning by comparing one BKI-standard plate material to determine stress and strain, it can be concluded that:

- The calculated static load is 29,577.15 N. The calculated total load is 165,128.41 N.
- The specifications of the material used for the main engine foundation model comparison are very influential due to the differences in the chemical composition mixture used in forming the steel plate, and the yield strength and tensile strength figures are very influential.
- The yield strength and tensile strength values in model A are 292 MPa and 430 MPa.
- The percentage comparison values of stress and strain show a significant difference, with a maximum simulation result difference and at 4 probe points, with a maximum stress result of 0.87% and strain of 0.44%. Then, at probe point A, the stress of the two models was 51.93%, with a difference in strain between the two models of 30.45%. At probe point B, the stress of the two models was >100%, with a difference in strain between the two models of >100%.
- At probe point C, the stress of both models was 48.15%, with a strain difference between the two models of 87.97%. At probe point D, the stress of both models was 5.82%. The strain difference between the two models was 44.11%.
- The minimum safety factor value is 0 μl and the maximum is 15 μl. Both models have 4 probe points for comparison of results: probe point A 30.43%, probe point B 15.89%, probe point C 30.43%, probe point D 25.29% with the highest safety level in model A at point A 0.3 μl, point B 1.75 μl, point C 1.87 μl, point D 1.09 μl.

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