Design of Cradle as a Tool for Inserting Shaft in New Shipbuilding Using Finite Element Methods

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Keywords: Cradle, Inserting Shaft, New Shipbuilding, Design, Finite Element Method.

Abstract: The shipbuilding industry in Indonesia has experienced very rapid development. Innovation methods in development have been improvised in time. In Indonesia, many shipyards have implemented the Full Outfitting Block System (FOBS) methods. This method, especially in the machinery outfitting process in the inserting shaft stage, takes a long time because it uses conventional methods with chain block tools. At PT. PAL Indonesia has historically carried out inserting shafts using a cradle on the Missile Destroyer Ship project (PKR) by recommendation from a foreign company and was able to minimize production time and costs. In supporting the sustainability of the work efficiency of new shipbuilding, cradle design is very much needed in the Inserting Shaft process on ships. The design process begins by making a design of 6 models of cradle variations that are tailored to the needs of the shipyard. All these design variations were then subjected to a strength analysis with the limits of allowable stresses and deflections from American Association of State Highway and Transportation Official (AASTHO). The stress and deflection values obtained from each variation of the design concept with all design concepts included in the allowable category.

1 INTRODUCTION

The shipbuilding industry in Indonesia has experienced very rapid development. Innovation methods in development have been improvised in time. In Indonesia, many shipyards have implemented the Full Outfitting Block System (FOBS) methods. This method, especially in the machinery outfitting process in the inserting shaft stage, takes a long time because it uses conventional methods with chain block tools. At PT. PAL Indonesia has historically carried out inserting shafts using a cradle on the Missile Destroyer Ship project (PKR) by recommendation from a foreign company and was able to minimize production time and costs.

In supporting the sustainability of the work efficiency of new shipbuilding, cradle design is very much needed in the Inserting Shaft process on ships, where improvement and proper engineering are needed for the inserting shaft process, this is very important to escalate and ensure safety, quality fulfilment, timely delivery. This will further reduce the production cost of shipbuilding. Design and analysis of the strength of the cradle construction in supporting the load of the ship's shaft in the Inserting Shaft process by paying attention to the position of the shaft bearing that supported the cradle. This analysis uses the finite element method using Fusion360 software to determine the maximum stress and maximum deflection that occurs in the cradle. Where the structure of the cradle must comply with the American Association of State Highway and Transportation Official (AASHTO).

2 INITIAL DESIGN

At the initiation stage of the cradle design, several reviews are needed of the components to be worked on.

2.1 Cradle

The cradle consists of two parts, namely train sled and shoes sled. A train sled or often referred to as a trolley is a type of conveyance whose operation method is pushed or handled by workers or operators manually

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in industrial plants or similar agencies. In general, a shoes sled shipyard is a tool used for the docking process (moving) the ship from the waters to the land for repairs. Skates or often referred to as sliding ways according to Meriam-Webster's Dictionary and Thesaurus are the bottom part of the cradle on which the ship is built and which slides over the ground when launched or raised (Dictionary, 2006).

2.2 Stress

Stress can be interpreted as the intensity of the force on the structural elements which is a reaction to the deformation that arises due to the work of external loads. Broadly speaking, stress is the magnitude of the force acting on each unit of cross-sectional area (Asroni 2017). So that stress can also be referred to as a force that can withstand a load (Macdonald 2002).

2.3 Deflection

Deflection is a condition of changes in the shape of the beam in the y-direction due to vertical loading given to the beam or rod. Deformation in the beam is very easily explained by the deflection of the beam from its position before being subjected to loading. The deflection is measured from the initial neutral surface to the neutral position after deformation. A structural system that is placed horizontally and which is mainly intended to carry lateral loads namely loads that act perpendicular to the axial axis of the rod (Hariandja, 1996). The maximum allowable deflection according to the American Association of State Highway and Transportation Official (AAHSTO) is the maximum deflection of the bridge construction (Restrepo 2002), not more than:

2.4 Deflection

The moment is the result of multiplying the force with the distance from the force to the point (Widiyanto 2013). The moment equation can be written in this Equation as refer rule regulation.

In the condition of the force that has a different capture point, where the point of capture of the force with each other has a distance so that the moment occurs. Then the number of moments at one point equal to zero can be seen in this equation as follows actual maximum bending moment.

2.5 Safety Factor

Safety Factor is a factor that shows the level of ability of an engineered material from external loads to handle pressure loads and tensile loads. The safety factor can be determined in equation 3 as follows (Budianto, Strength Structure Analysis of Main Gate Graving Dock Using 2018).

The value of the safety factor must be greater than 1.0 in order to avoid failure. If the factor of safety is very low, the probability of failure will be high, and the structure will not be acceptable. If the factor of safety is too large, the structure will be wasteful of materials and may not be suitable for its function, e.g., too heavy. Due to this complexity and uncertainty, the factor of safety must be determined probabilistically. The following is the Typical Overall Factor of Safety table according to the Mechanical Engineer's Data Handbook as follows (Carvill 1993).

	Type of load			
Material	Steady	Varying, of same kind	Alternating	Shock
Grey cast iron	4	6	10	15
Malleable cast iron	4	6	8	12
Carbon steel	4	6	8	12
Brittle alloys	5	6	10	15
Soft alloys	5	6	8	12
Timber	6	10	14	20
Brick	15	20	25	30
Stone	15	20	25	30

Figure 1: Typical factor of safety for various materials.

Component	FS	Component	FS
Boilers	4.5–6	Gears: static load	1.25
Shafts for flywheels, armatures, etc.	7–9	fatigue load	2.0
Lathe spindles	12	Wire rope: general hoists	5–7
Shafting	24	guys	3.5
Steelwork: buildings	4	mine shafts	5–8
bridges	5	lifts	7 12
small-scale	6	Springs: small, light duty	2
Cast-iron wheels	20	small, heavy duty	3
Welds not subject to fatigue	3–6	large, light duty	3
Turbine blades and rotors	3–5	large, heavy duty	4.5
Bolts	8.5		

Figure 2: Typical factor of safety for various components.

2.6 Load

Loading is a load that burdens a construction in the form of object weight, wind strength, and wind weight (Priambodo, 2011). These charges have magnitude, direction, and line of action. In the cradle construction that has been made, there is only one loading, namely vertical loading (M.Gere and S.P.Timoshenko 1994).

2.7 Finite Element Method

The finite element method was originally used to solve complex problems in the field of Civil

Engineering and Aeronautical Engineering, especially on elasticity problems and structural analysis (Budianto, Analisis Kekuatan Struktur pada Kapal Wisata Sungai Kalimas 2015). This is much more practical and economical when designing a design before making it a physical prototype (Naruto, 2019). The finite element method is a numerical method used in solving problems in various engineering fields such as the geometry, loading, and properties of very complex materials. In addition, this method can also be used to solve structural, thermal, and electromagnetic problems (Morna 2012). Problem-solving in the finite element method is a solution approach to find the displacement of the element's discrete nodes and the strength of the structure (Budianto, Strength Structure Analysis of Main Gate Graving Dock Using 2018).

In this method, all complex problems such as variations in shape, boundary conditions, and loads are solved by an approximation method. The finite element method approach uses the information at the node. In the process of determining the node points called discretization, a system is divided into smaller parts, then problem-solving is carried out on these parts and then recombined to obtain a comprehensive solution (Logan 2005). The descriptions carried out can be in the form of one-dimensional elements (line elements), two-dimensional (shell field elements), or three-dimensional (solid elements or continuum) (Budianto, 2018). In structural analysis, the finite element method analysis can be used to solve deflections and stresses in complex structures that receive certain loads at appropriate boundary conditions (Asmara and Budianto 2016)

3 CONCEPT DESIGN

Collecting data to support the design process is a General Arrangement of Shaft Line design drawing of the highest weight ever produced by PT. PAL Indonesia (Persero). In addition, in planning the cradle design, comparative design data is needed as a basis for planning dimensions for making a new design on the cradle where this data is taken from the cradle design that has been used before by the company. The data that has been collected will be used as a basis for designing and planning the shape of the cradle. The general arrangement of the Shaft Line is used to determine the load borne by the planned Cradle.

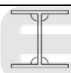
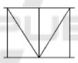
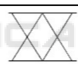
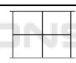
In this case, because the load supported by the cradle is a shaft that has a relatively heavy weight, the cradle is designed with materials that can be found on the market and are also economical in price so that the material is obtained in the form of plate-shaped steel with ASTM 36 type with specifications as shown in the following table.

Table 1: Specification of ASTM 36 steel.

ASTM A36 Steel		
Mechanical Properties	Ultimate Tensile Strength	400–550 MPa
	Yield Tensile Strength	250 MPa
	Elongation at Break (200cm)	20,0 %
	Modulus of Elasticity	200 GPa

After obtaining supporting data, the next step is planning from the cradle shape. In this planning, the sled design is made with almost the same shape as the sled that has been used before because the shape adjusts to the shape of the pedestal of the shaft that has been planned by the vendor and for the skates, variations are made with different girder shapes and construction patterns as shown in the following table.

Table 2: Variations of design.

Part	1	2	3
Girder (G)	 I Shape	 Hollow	
Pattern (P)	 Triangle	 Cross X	 Square Box

From these variations, a model will be made with the following scheme.

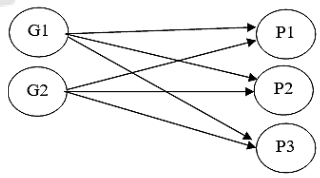


Figure 3: Design Variation Relationship Patter.

The cradle consists of a train sled and shoes sled with cradle modeling done using Fusion 360 software as follows.

Figure 4: Design of the Shoes Sled Variations.

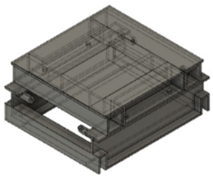


Figure 5: Design of the Train Sled.

In the assembly of the cradle, it is necessary to plan the positioning of the pedestal of the cradle, where it is planned that one cradle has three supports which are placed at both ends and the middle position of the cradle as shown in the following schematic image.

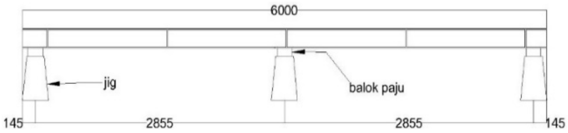


Figure 6: Cradle Leg Arrangement Sketch.

This cradle has a load in the form of a shaft placed on a sled with a configuration that adjusts to the bearing position that has been planned by the maker of the shaft in the shaft dimension drawing and the following shaft bearing arrangement.

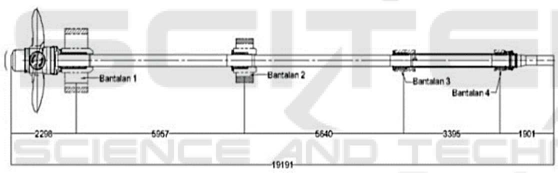


Figure 7: Shaft Dimensions and Shaft Bearing Arrangement.

It is necessary to calculate the load at each point of the shaft bearing to obtain the load value that will be used as a reference for strength analysis. From the dimension and arrangement data, it can be used as a reference in calculating the load that will be borne by the cradle at each point of the shaft bearing by carrying out the calculations illustrated in the following sketch.

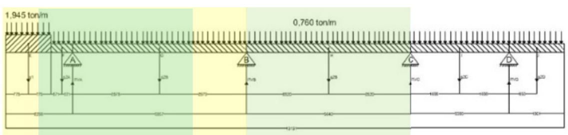


Figure 8: Shaft Load Distribution Sketch.

This calculation can be done using the equation of moment and balance. The moment is the result of multiplying the force with the distance from the force to the point (Widiyanto, 2013), which can be written with equations 1 and 2 with the following calculations.

$\sum M_A$
$= 0$
$(-3.026 \text{ ton} \times 1.5200 \text{ m}) - (0.564 \text{ ton} \times 0.3710 \text{ m}) + (4.527 \text{ ton} \times 2.9753 \text{ m}) - (RVB \times 5.9570 \text{ m})$
$= 0$
$8.6749055 - 5.957 \, RVB$
$= 0$

$\boxed{\mathbf{RV_B} \;=\; 1{,}456254871}$

$\sum M_B$
$= 0$
$(4.527 \text{ ton} \times 2.978 \text{ m}) - (RVA \times 5.957 \text{ m}) + (0.564 \text{ ton} \times 6.328 \text{ m}) + (3.026 \text{ ton} \times 7.477 \text{ m})$
$= 0$
$39.6758 - 5.957 \, RVB$
$= 0$

$\boxed{\mathbf{RV_A} \;=\; 6.660365456}$

$\sum M_B$
$= 0$
$(4.286 \text{ ton} \times 2.820 \text{ m}) - (RVC \times 5.640 \text{ m})$
$= 0$
$12.08652 - 5.640 \, RVC$
$= 0$

$\boxed{\mathbf{RV_C} = 2.143 \text{ ton}}$

$\sum M_C$
$= 0$
$(4.286 \text{ ton} \times 2.820 \text{ m}) - (RVB \times 5.640 \text{ m})$
$= 0$
$12.08652 - 5.640 \, RVB$
$= 0$

$\boxed{\mathbf{RV_B} = 2{,}143 \text{ ton}}$

$\sum M_C$
$= 0$
$(2.580 \text{ ton} \times 1.697 \text{ m}) - (RVD \times 3.395 \text{ m}) + (1.445 \text{ ton} \times 4.3455 \text{ m})$
$= 0$
$10.6575075 - 3.395 \, RVD$
$= 0$

$\boxed{\mathbf{RV_D} \;=\; 3{,}139177467}$

$\sum M_D$
$= 0$
$(-1.442 \text{ ton} \times 0.9505 \text{ m}) + (2.580 \text{ ton} \times 1.697 \text{ m}) - (RVC \times 3.395 \text{ m})$
$= 0$
$3.0047875 - 3.395 \, RVC$
$= 0$

$\boxed{\mathbf{RV_C} \;=\; 0.885062592}$

After calculating the value of the reaction force, correction is made by comparing the values of q_1, q_{2A}, q_{2B}, q_{2C}, q_{2D}, and q_{2E} with RV_A, RV_B, RV_C, and RV_D equal to one with the following calculations.

$$\text{Correction} = (3.02642 + 0.56392 + 4.52732 + 4.2864 + 2.5802 + 1.44475) / (6.660365456 + 3.599254871 + 3.02806392 + 3.139177467)$$

$$= 16.43 / 16.43$$

$$= 1 \textbf{ (accepted)}$$

From the calculation of the value of the reaction force, the shaft load point can be taken for simulating cradle loading with the summary in the following table.

Table 3: Summary of Shaf Load Value.

Pos.	Load Value
A	6.660365456 ton
B	1.456254871 + 2.143 = 3.599254871 ton
C	2.143 + 0.885062592 = 3.028062592 ton
D	3.139177467 ton
Total	**16.43 ton**

After obtaining the load value at each supported point, then the highest load value is taken, namely 6.66 tons, as the load value for the simulation. Because this is a design process, it is necessary to carry out further calculations to determine the design load value as in equation 4 with the following calculations.

$$P_{design} = 6.660 \text{ kg} \times 1,25$$

$$= 8.325 \text{ kg}$$

$$F_{design} = 8.325 \text{ kg} \times 9,81$$

$$\mathbf{= 81668.25\ N}$$

After obtaining the Fdesign value, then a strength analysis is carried out. To obtain accurate finite element analysis results, it is necessary to adjust the element size by conducting a meshing convergence test. So that the element size is 150mm as shown in the following graph.

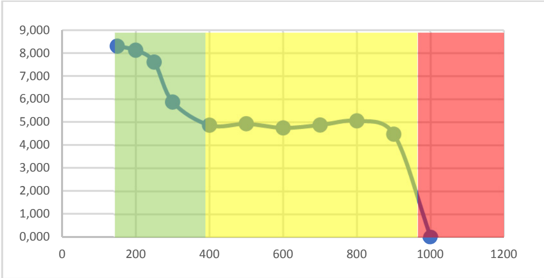


Figure 9: Meshing Convergence Graph.

4 RESULT AND DISCUSSION

After obtaining the F design value, a meshing convergence test was carried out and the element size was obtained at 150mm, then a simulation of each design concept was carried out with a perfect circuit together with the train sled. The maximum stress results from the simulation are compared to the maximum allowable stress value that occurs in structures having a Safety Factor (SF) of 5.0 in the typical overall safety of factor table (referring to Tables 1 & 2) so that the bending stress value is obtained. The maximum of the cradle is.

The maximum deflection results from the simulation are compared to the maximum allowable deflection value in accordance with the regulations of the American Association of State Highway and Transportation Official (AAHSTO) as in equation 1 is shown below.

The simulation can be done with Fusion 360 software by inputting the type of material, the constraints on the cradle legs, and also the size of the elements according to the convergence results of 150 mm. so that the simulation results are obtained in each of the following six models.

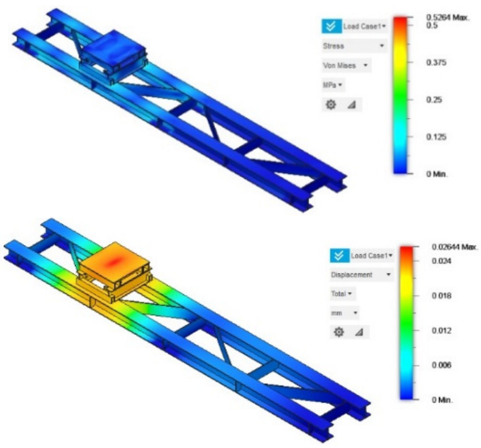


Figure 10: (a) Stress Result of Model 1; (b) Displacement Result of Model 1.

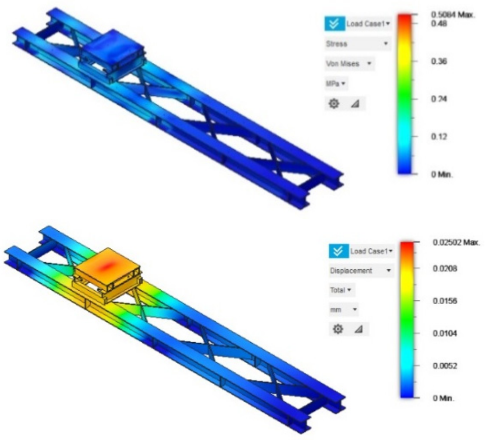


Figure 11: (a) Stress Result of Model 2; (b) Displacement Result of Model 2.

Figure 12: (a) Stress Result of Model 3; (b) Displacement Result of Model 3.

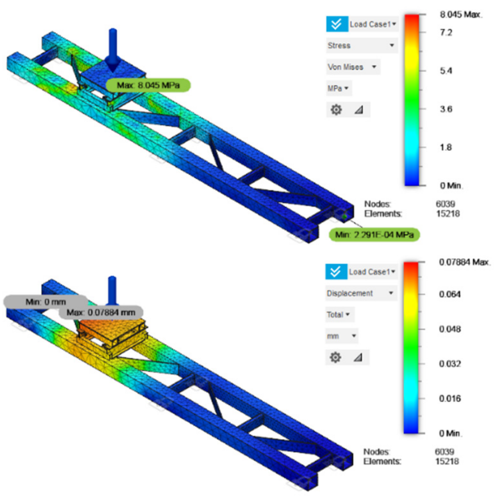


Figure 13: (a) Stress Result of Model 4; (b) Displacement Result of Model 4.

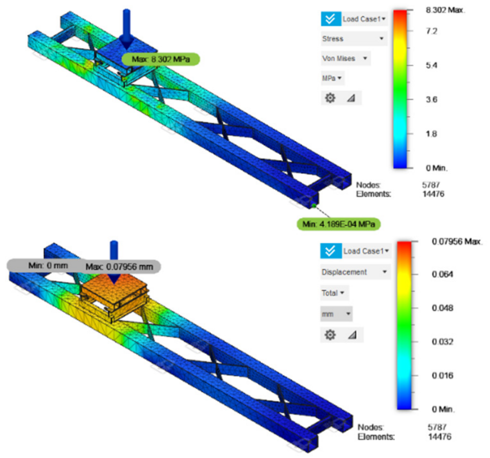


Figure 14: (a) Stress Result of Model 5; (b) Displacement Result of Model 5.

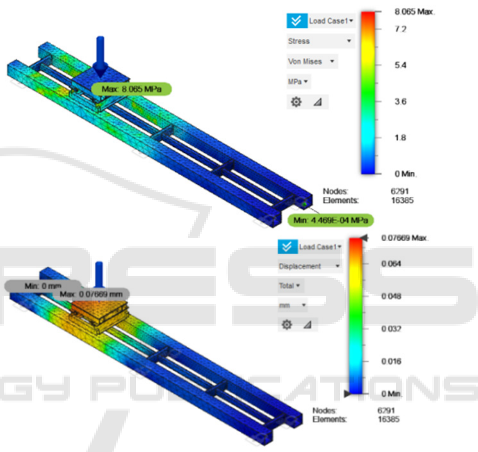


Figure 15: (a) Stress Result of Model 6; (b) Displacement Result of Model 6.

From all simulation results, each stress and displacement value is obtained, then validation is carried out with the allowable stress and permit displacement which have been calculated according to regulations and the results are obtained in the following table.

Table 4: Strength analysis results.

Model	Type of Analysis	Maximum	Allowable	SF	Status
1	Stress	0.526 N/mm^2	110 N/mm^2	5	Allowed
	Displacement	0.026 mm	1.586 mm		Allowed
2	Stress	0.508 N/mm^2	110 N/mm^2	5	Allowed
	Displacement	0.025 mm	1.586 mm		Allowed
3	Stress	0.098 N/mm^2	110 N/mm^2	5	Allowed
	Displacement	0.005 mm	1.586 mm		Allowed
4	Stress	8.045 N/mm^2	110 N/mm^2	5	Allowed
	Displacement	0.079 mm	1.586 mm		Allowed
5	Stress	8.302 N/mm^2	110 N/mm^2	5	Allowed
	Displacement	0.080 mm	1.586 mm		Allowed
6	Stress	8.065 N/mm^2	110 N/mm^2	5	Allowed
	Displacement	0.077 mm	1.586 mm		Allowed

5 CONCLUSIONS

The cradle is designed with ASTM 36 Steel material with 6 different models, where in the analysis results the six models are in the conditions allowed by regulation. of the six models, model 3 has a relatively lower stress value than all models with a value of 0.098 N/mm^2 and also has a relatively lower displacement value than all models with a value of 0.005 mm. So that model 3 has a tendency to be used as a reference model in making the cradle because it has a higher strength than all the models made.

The 3rd concept cradle is made in the form of a girder I shape. This concept shoes sled is given a reinforcement construction with a square box pattern made of 12 mm thick plate and for the middle reinforcement made of 10mm thick plate, both of which have been adjusted to the position of the welder during welding.

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