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Effect of Lifting Lug Hole Diameter Size on Strength Performance in Ship Block Lifting Process

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FEM
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Stress

ABSTRACT – The safety of the ship block lifting process is always a serious concern during the assembly of ship blocks. The block/structure and equipment must not be damaged during the lifting process. This study aims to determine the structural response values that occur with various hole diameter sizes of the lifting lug during the ship block lifting process. The object of this research is a ship block from the new construction of the Ferry Ro-Ro 1500 GT. The method used is numerical simulation based on finite element method (FEM) software. The simulation is conducted to obtain the stress and deformation values for each size of the lifting lug. The selected ship block load is the largest ship block load, which is 52,380 tons. The number of lifting lugs used in the simulation is 5, with varying diameters of 53, 58, 63, 68, and 73 cm. Based on the simulation results, the diameter of 63 mm gets the minimum normal and shear stress figures. While the minimum von misses stress figure is shown by the variation of the diameter of 73 mm. While the smallest deformation figure is shown by the variation of the diameter of 53 mm. In general, all variations of lifting lug holes can still be applied with the note that the weight of the load must be considered.

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INTRODUCTION

The safety of lifting process is the most important part of any construction in ship repair or new building process. With the development of the modern shipbuilding industry, the construction of offshore and ship structure blocks is now in the region of hundreds to thousands of tons [1]. Block transportation and changeover are important operations in shipbuilding and offshore construction processes [2]. As is known, lifting lug is a part of a ship or offshore structure. Lifting lug is used to lift and turn the block during the lifting process. In the manufacture of ships or offshore structures to improve the efficiency of the block lifting process. Part of the block is designed to be made in terms of saving the selection of optimal location and determining the optimal amount required to lift and turn the ship block [3].

Lifting lug is a semicircular object made of metal and welded to a plate. Lifting a ship block is a sensitive process because the lifting block must be installed in the correct and efficient position. What needs to be considered in the process lifting is the safety of the block to be lifted, as well as the equipment and supplies used in lifting [4]. The block/structure and equipment must not be damaged during the lifting process. Amount lifting lug used depends on the size and weight of the block. Lifting lug usually 4 pieces are used to keep the block stable during the process. In this study, the failure of welded joints often affected by microstructure degeneration or large tensile stress or corrosive media. The most common and serious failure in welded joints is the transition from ductile fracture to brittle fracture caused by high temperature and high pressure [5].

In the process of constructing a new building, the lifting process is essential specialy in ship block assembly. There is a shipyard in Indonesia working on the construction of a new 1500 GT Ro-Ro ferry. At the shipyard, ship blocks are positioned using a lifting process. During the lifting process, lifting lugs are necessary to assist in placing the ship blocks. The purpose of using lifting lugs is to prevent damage to the ship blocks during the lifting process. The size of the ship blocks must match the weight of the block on the ship. The lifting lugs used must be properly calculated to ensure that the ship block lifting process smoothly. In this research, the issue to be addressed is related to the diameter of the lifting lug hole that is suitable for the ship block lifting process of a Ferry Ro-Ro 1500 GT. The aim of this research is to obtain the minimal structural response values of the lifting lug, such as stress and deformation with hole diameter variations. The simulation of the ship block lifting process will be conducted using software based on the finite element method (FEM), this method has been widely used in various application rangin from application in offshore structure [6],in many type of ships such as traditional fishing vessel [7] [8], ferry ro-ro [9], SPOB (Self-

Propelled Oil Barge) [10], until alternative material [11]. The lifting lugs data obtained from the field are very wasteful in terms of material usage [12] when used in the ship block lifting process.

In this study, the ship block model will not be modeled. The Ship Block is assumed as a load acting on the lifting lug structure. The boundary conditions applied in this simulation are the welding between the lifting lug and the ship block assumed as a fix support. Where, all directions of movement are considered non-existent (ux, ut, uz, rx, ry, rz = 0). This condition approach is expected to approach the conditions in the field.

METHOD

Lifting Lug Data

The lifting lug modeling represents the load case that will be pulled. Therefore, the selection of the appropriate symmetric and asymmetric geometry for the lifting lug to be designed is crucial. Symmetric lifting lug geometry is used for vertical loading cases with sling angles up to 60º from the horizontal/base of the lifting lug. Asymmetric lifting lug geometry is used in heavy lifting with a single flat plate on both sides of the main plate for lashing operations. In the asymmetric geometry, the shackle connecting the lifting lug and sling works under a pull angle. The center of the pinhole is located above the main plate because the sling works under a 6-degree angle to the main plate. The forces acting will be at the same angle. Therefore, the force can be divided into vertical (Fy) and horizontal (Fx) components. The lifting lug are widely used in the shipbuilding and offshore industries. A good lifting lug design must ensure high safety while also being cost-effective [13]

The lifting lug dimensions were obtained from field measurements of a ship block. Design considerations were based on the heaviest block, weighing 52.380 tons. For blocks exceeding 10 tons, four lifting lugs are installed, resulting in each lug bearing approximately 13.095 tons. Figure 1 shows the shape of the lifting lug models used in this study. The material properties of the lifting lug are based on the specifications of higher strength steel plate as per the BKI material regulations in Volume V [14], as show Table 1.

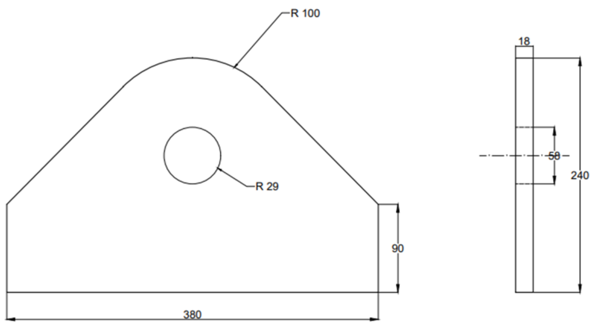


Figure 1. Geometry of Lifting Lug

Table 1. Material Properties of Lifting Lug

Description	Mark
Density	7850 kg/m3
Tensile yield strength	355 MPa
Compressive yield strength	355 MPa
Tensile ultimate strength	490 MPa
Young's module	200 GPa

Governing Equation

Stress is a quantity that indicates the internal force between particles of a material acting on each other. When the lifting lug is pulled with a force, the stress is tensile stress. In the present study, numerical simulation is used to determine the stress. Previously, we have conducted many experiment to determine the stress in many cases [15-18]. Furthermore, if the force acts in the opposite direction, causing the bar to compress, compressive stress occurs. Therefore, normal stress can be either tensile or compressive. Shear stress, on the other hand, is stress that acts tangentially to the surface of the material [19]. The allowable stress is the maximum stress required by the classification body. The stress resulting from an unlimited load on a structural element, without causing fracture, deformation, or shape change. The determination of the allowable stress is crucial for the calculation and inspection of the structural dimensions [20].

Stress is the force that acts perpendicular (normal) to the surface of the working plane. Stress occurs due to axial force and bending. Stress can be symbolized by sigma (σ), as shown in equation 1.

$$\sigma = \frac{F}{A} \quad (1)$$

Where,

σ = normal stress (N/mm^2)

F = force (N)

A = section area (mm^2)

The equation for shear stress is given in equation 2.

$$\tau = \frac{v}{A} \quad (2)$$

Where,

τ = shear stress (N/mm^2)

v = shear force (N)

A = Section Area (N/mm^2)

Von Mises stress is a combination of all stress values within a structural system. It is used in the stress analysis of ductile materials. Von Mises stress analysis defines yielding as failure, so the result obtained from this analysis represents the tensile stress value within the structure. The magnitude of the Von Mises stress is calculated using the following equation 3.

$$\sigma_{VM} = \sqrt{I_1^2 - 3_2^I} \quad (3)$$

$$I_1 = \sigma_x + \sigma_y + \sigma_2 \quad (4)$$

$$I_2 = \sigma_x\sigma_y + \sigma_y\sigma_z + \sigma_z\sigma_x - \tau_{xz}^2 - \tau_{yz}^2 - \tau_{xy}^2 \quad (5)$$

Where,

σ_{VM} = Von Misses Stress (N/mm^2)

I_1 = Stress Invariant 1

I_2 = Stress Invariant 2

σ_x = normal stress in x direction

σ_y = normal stress in y direction

σ_z = normal stress in z direction

τ_{xy} = shear stress in x surface

τ_{yz} = shear stress in y surface

τ_{xz} = shear stress in z surface

The Finite Element Method (FEM) is a numerical technique used to solve engineering and physical problems, particularly in structural analysis, heat transfer, and fluid dynamics. FEM works by dividing a complex domain into smaller elements (a mesh) that are interconnected at specific points called nodes. Each element is assigned local material properties, and the entire system is analyzed by assembling a global stiffness matrix. The fundamental equation of FEM is :

$$[K]\{u\} = \{F\} \quad (6)$$

Where,

[K] = Global stiffness matrix

$\{u\}$ = nodal displacement vector

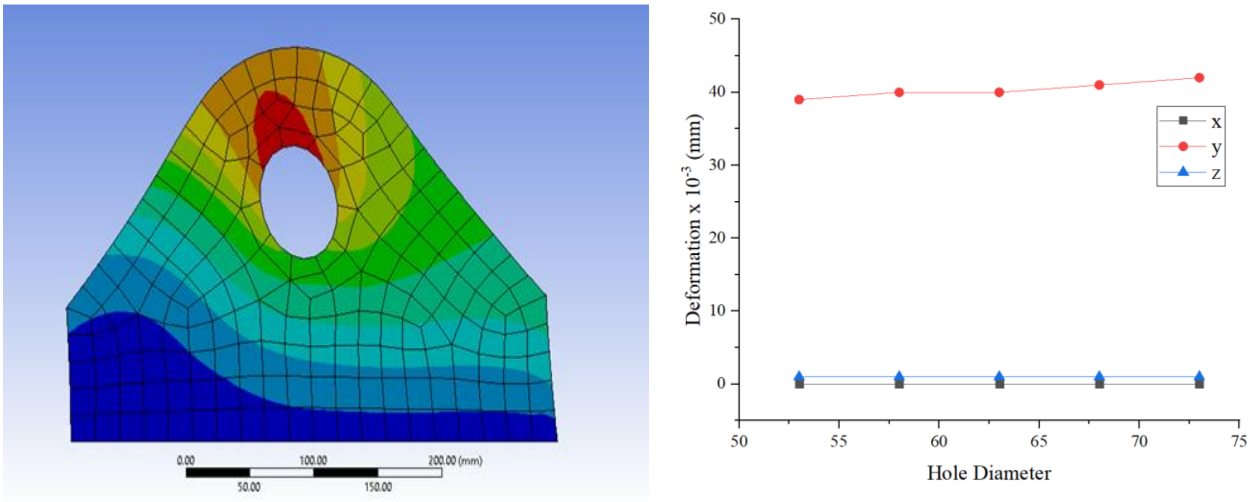
$\{F\}$ = nodal force vector

RESULTS AND DISCUSSION

From the analysis results, we will review the normal stress, shear stress, von mises stress, and maximum deformation of the model lifting lug. Where, the variation diameters of lifting lug are 53, 58, 63, 68, and 73 cm. In each stress and deformation analysis that occurs, the results of each X, Y, and Z axis will be displayed. Below are the results of the stress and deformation in each design. The lifting load angle will also be varied. The ship block lifting angle simulated is 70°. The following section presents an explanation of the results obtained from the computer-based simulation

Deformation

In FEM analysis, deformation checking is always done to see the behavior of changes in the shape of a structure. In this lifting lug, the deformation behavior after receiving the ship block load can be seen in Figure 2. Usually, the high and low deformation values are depicted from the color gradation that occurs. Based on Figure 2, the change in the shape of the lifting lug tends to follow the direction of the incoming force.



Gambar 1. Deformation Distribution on Lifting Lug

Table 2. Lifting Lug Deformation

No	Hole Diameter of Lifting Lug	Deformation (mm)		
		x	y	z
1	53	0.000	0.039	0.001
2	58	0.000	0.040	0.001
3	63	0.000	0.040	0.001
4	68	0.000	0.041	0.001
5	73	0.000	0.042	0.001

Table 2 shows the deformation values in the x, y, and z directions for different lifting lug hole diameters. The simulation results indicate that deformation in the x and z directions remains nearly constant at 0.000 mm and 0.001 mm, respectively, across all diameter variations. However, a slight increase in deformation is observed in the y direction as the hole diameter increases. The lowest deformation in the y direction (0.039 mm) occurs at a hole diameter of 53 mm, while the highest (0.042 mm) is recorded at a diameter of 73 mm. This suggests that the hole diameter has a minor but noticeable effect on deformation in the vertical direction

Normal Stress

For normal stress, the highest stress occurs in the area around the lifting lug hole as seen in Figure 2. The red color indicates the highest stress occurs in that area. This normal stress is greatly influenced by the cross-sectional area of a structure.

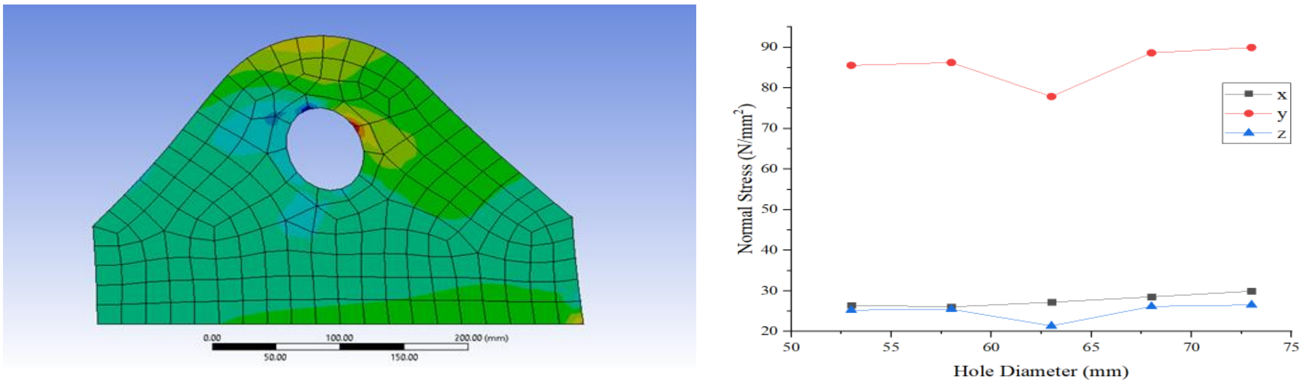


Figure 2. Distribution of Normal Stress

Table 3. Normal Stress of Lifting Lug

No	Hole Diameter of Lifting Lug	Normal Stress (N/mm^2)		
		x	y	z
1	53	26.477	85.567	25.266
2	58	26.075	86.264	25.466
3	63	27.223	77.893	21.382
4	68	28.529	88.644	26.166
5	73	29.929	89.978	26.562

Table 3 presents the normal stress values in the x, y, and z directions for various lifting lug hole diameters. The results show variations in stress across all directions as the hole diameter increases. The highest normal stress in the y-direction (89.978 N/mm²) is observed at a hole diameter of 73 mm, while the lowest (77.893 N/mm²) occurs at 63 mm. Interestingly, the lowest stress values in all three directions are generally recorded at a diameter of 63 mm, especially in the y and z directions, indicating that this diameter may be the most efficient in minimizing stress. Conversely, larger diameters (68 mm and 73 mm) result in higher stress values, particularly in the y-direction, which may indicate less favorable stress performance.

Shear Stress

This stress occurs when a force is applied not perpendicularly, but sideways or parallel to the surface of an object, causing parts of the material to shift relative to each other. The process begins when a force is applied to an object parallel to its surface, rather than perpendicular to it. As a result of the force, the layers in the object begin to slide relative to each other. The upper layers tend to move, while the lower layers are held back. The friction between the layers causes shear stresses to develop in the material—these are internal forces that keep the object from breaking or deforming too quickly. If the force is large enough, the object begins to deform. The angle between the initial line and the line after the force is applied also changes. Basically, the shear stress that occurs in each simulation is still in the safe category. There is no peak stress between each variation of hole diameter. The highest shear stress occurs in the area around the lifting lug hole as seen in Figure 3.

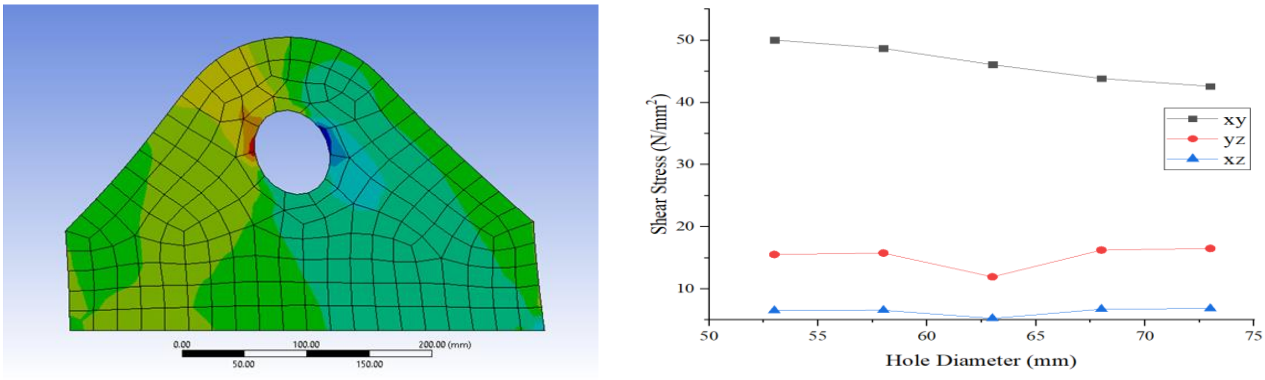


Figure 3. Shear Stress Distribution

Table 4. Shear Stress of Lifting Lug

No	Hole Diameter of Lifting Lug	Shear Stress (N/mm^2)		
		xy	yz	xz
1	53	50.067	15.535	6.510
2	58	48.724	15.764	6.570
3	63	46.090	11.935	5.256
4	68	43.862	16.254	6.735
5	73	42.601	16.507	6.836

Table 4 presents the shear stress values in the xy, yz, and xz planes for different lifting lug hole diameters. The data indicate that shear stress generally decreases as the hole diameter increases, especially in the xy and xz planes. The lowest shear stress values in all directions are observed at a hole diameter of 63 mm, with 46.090 N/mm² in the xy plane, 11.935 N/mm² in the yz plane, and 5.256 N/mm² in the xz plane. These results suggest that the 63 mm diameter provides a more efficient stress distribution under shear loading. Conversely, the largest diameter (73 mm) exhibits slightly higher stress values in the yz and xz planes, although it maintains the lowest value in the xy plane.

Von Misses Stress

Von misses stress is a structural response due to a combination of tensile forces that produce normal stress and shear stress from various directions. This von misses stress is a value used by engineers to predict structural failure. In general, the von misses stress results are still in a safe stage because the value is still below the allowable stress of the material. However, the phenomenon of stress distribution in each area is different, unlike the normal and shear stress responses. The largest von misses stress is actually shown in the lifting lug and ship block connection area which is assumed to be a clamped support as shown in Figure 4.

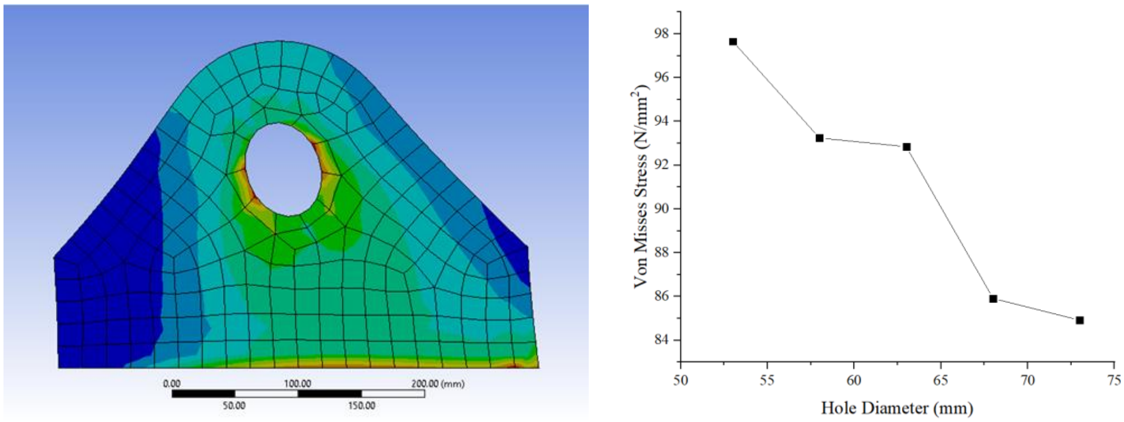


Figure 4. Von Misses Stress Distribution

Table 5. Von Misses Stress of Lifting Lug

No	Hole Diameter of Lifting Lug	Von Misses Stress (N/mm^2)
1	53	97.658
2	58	93.244
3	63	92.846
4	68	85.917
5	73	84.920

Table 5 presents the Von Mises stress values for different lifting lug hole diameters. The results show a general decreasing trend in Von Mises stress as the hole diameter increases. The highest stress is observed at a diameter of 53 mm with a value of 97.658 N/mm², while the lowest is at 73 mm with 84.920 N/mm². Although the 73 mm diameter yields the lowest Von Mises stress, the 63 mm diameter offers a slightly higher stress value (92.846 N/mm²) while also showing optimal results in terms of normal and shear stress. This suggests that the 63 mm hole diameter may represent a balanced option between structural performance and material efficiency

CONCLUSION

A computer-based FEM simulation on a lifting lug with varying hole diameters has been successfully carried out. The simulation results show that the hole size in the lifting lug affects the magnitude of the resulting stress. However, this is not the case with the deformation values. The deformation in each axis direction shows a similar trend. For normal stress and shear stress performance, the variation of 63 mm gets the minimum value. While the smallest von misses stress value is obtained by the variation of 73 mm. So the recommended ideal hole size for ship block lifting operations in this case is 63 and 73 mm. However, the conclusion of this study still requires further study, especially the effect of the lifting angle, the effect of installing a stopper on the lifting lug and the effect of the thickness of the lighting lug.

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