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An investigation of strength degradation due to thickness plate reduction on Ferry Ro-Ro Ship's Hull

A M Nugraha A[1*], M U Pawara[1], A Ardianti[2], F Mahmuddin[3]

[1] Naval Architecture Program, Department of Science, Food Technology, and Maritime, Kalimantan Institute of Technology, Balikpapan, Indonesia
[2] Naval Archirecture Department, Engineering Faculty, Hasanuddin University, Makassar, Indonesia
[3] Marine Engineering Department, Engineering Faculty, Hasanuddin University, Makassar, Indonesia

*Corresponding author: andi.mursid@lecturer.itk.ac.id

Abstract. Old ships will experience a degradation of the structural strength after receiving repeated loads. Decreased strength performance is also caused by structure shape and structural dimensions changes. In steel ships, Dimensional changes will be discovered when the ship is docked, because the material undergo corrosion causing in thinning the shell plate. In this study, a thickness reduction of the shell plate has been simulated to determine the longitudinal response of the ship's structure. A Finite element analysis of ferry Ro-Ro ship's hull was carried out using ANSYS package program. The simulation was carried out to exceed the allowable limit for reducing the thickness plate by the Indonesian Classification Bureau (BKI), which is 20% of the initial plate thickness. Based on simulation result, it was found that an increase of stress at each variation of the reduction in hull plate thickness in hogging and sagging conditions.

1. Introduction

Ferry Ro-Ro is a sea transportation mode is mainly found in archipelago countries, and has a very strategic function as a bridge between islands like in Indonesia. Technical attention to this ship is very important to make the basis of its operational safety. In Indonesia, there are many cases of operational failure on the ferry ro-ro, one of which is KMP Lestari Maju in 2018. Based on KNKT Report, the investigation found that the corrosion in the several constructions was not repaired [1].

Research on longitudinal ship strength due to changes in construction has been carried out by many researchers such as studies of longitudinal strength due to laying longitudinal beams on tankers [2], application of FEM to the ultimate strength of hull longitudinal beams due to asymmetric damage [3]. In general, the structure of a steel ship is a complex construction unit that must be able to withstand the loads acting on the structure. These loads can be static loads (cargo, machinery and ship structures) and dynamic loads such as wind, wave and ice loads [4]. The possible reasons of ship structure failures are structural damage due to collisions, aged and corroded plates [5].

Under normal conditions, a thickness reduction of the hull plate is inevitable because the ship operates in corrosive environment. So that this phenomenon will continue to occur in all steel ships. Considering this condition, it is necessary to arrange a maintenance scheduling of ship by first knowing the effect of thickness reducing on the hull plate. Based on this reason, this study will conduct a reduction thickness simulation of the hull plate. The object of research was the Ferry Ro-Ro 750 GT. As an illustration, the Ro-Ro ferry is one type of the most use sea transportations and has advantages for a short-sea trips. Ro- Ro vessels have built-in ramps which allow the cargo to be efficiently "rolled on" and "rolled off" the vessel when in port [6]. The ramp and doors may be sternonly or bow and stern for quick loading as shown in Figure 1.

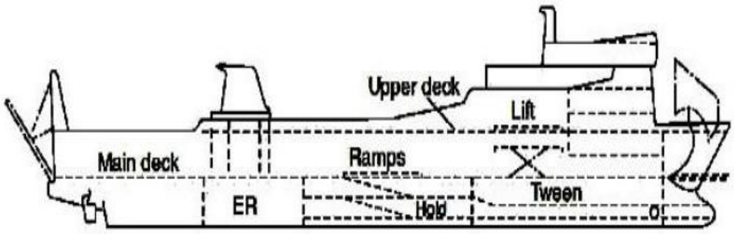


Figure 1. General Layout of Ro-Ro Vessel [6]

This study aims to investigate the longitudinal response of the ship structure due to thickness change. Finite element method (FEM) is applied to obtain the stress in the ship structure. The ship hull will be modeled in one compartment between the bulkheads in the parallel middle body. The shape of the thickness reduction of the shell plate is made uniform until to the maximum draught. Finally, the vertical bending moment is applied in both sagging and hogging conditions.

2. Methods

2.1 Ferry Ro-Ro data

The ship used in this study has a transverse framing system. In this type of construction, the ship is equipped with transverse stiffeners such as the longitudinal deck beam which is installed to the deck car, and the transverse stiffener is tightened on the main and web frames which are connected to the wrong plate on each them. The data used this study are as follows:

Ship Type	: Ferry Ro-Ro 750 GT
LOA	: 68.00 m
B	: 15.00 m
H	: 3.20 m
T	: 2.00 m

Plate material on ships uses steel plate grade A, mild steel category based on BKI Rules with the following material specifications:

Modulus Young (E)	: 210000 N/mm^2
Poison Ratio (√)	: 0.3
Yield stress (Se)	: 235 N/mm^2
Tensile stress (Su)	: 400 – 520 N/mm^2

2.2 Ship structure modeling

This research requires a key plan drawing for finite element modeling. Finite element analysis (FEA) is carried out by dividing the ship structure into small parts to determine the stress and deformation that occurs in each structure. The part of the ship to be analyzed is located on frame 59-79. This section is chosen because it has the longest transverse bulkhead distance when compared to other bulkheads. This frame is located around the hull, which is assumed having the greatest moment. Based on the rules of BKI volume II section 2, the biggest vertical moment due to hogging and sagging conditions is located in the middle of the ship which is 0.4 - 0.65 L [7]. The FE model of the modeled hull construction can be seen in Figure 2.

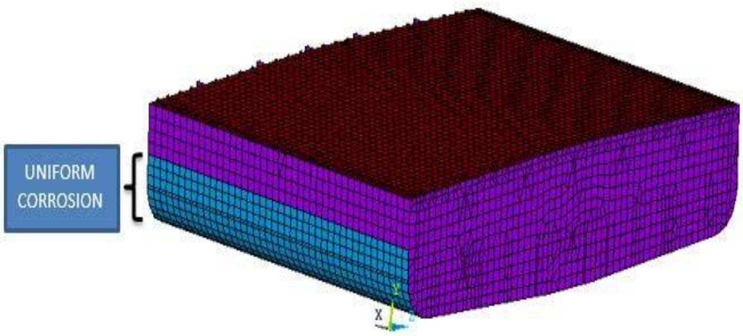


Figure 2. FE Model of Ship Hull Compartment

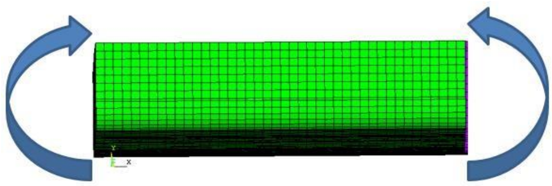
In the FE model, the thickness of the keel, bottom, bilga and side plates will be varied. The thickness reduction is 5% - 25% from initial thickness with an increment of 5%. The shell plate thickness value for each variation can be seen in Table 1.

Table 1. Variations in the reduction of shell plate thickness

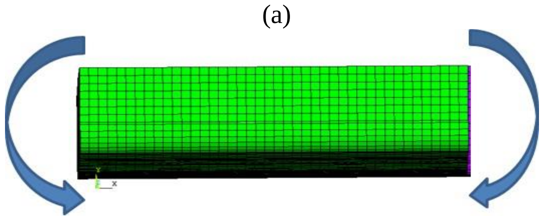
No	Plates	Initial Plate Thickness (mm)	Percentage reduction in thickness (mm)				
			5%	10%	15%	20%	25%
1	Keel Plate	12	11.40	10.83	10.29	9.77	9.29
2	Bottom Plate	10	9.5	9.03	8.57	8.15	7.74
3	Bilga Plate	10	9.5	9.03	8.57	8.15	7.74
4	Side Plate	10	9.5	9.03	8.57	8.15	7.74

2.3 Load condition

The load used in the FE model is the wave load which causes hogging and sagging conditions on the ship structure as shown in Figure 3.



(a)



(b)

Figure 3. Illustration of loading model: (a) sagging condition; (b) hogging condition

The load acting is calculated using the equation by the BKI 2021 (Volume II section 5) for hogging and sagging conditions. Where the vertical wave bending moment at the center of the ship is determined by the following equation [7] :

$$Mwv = L^2 \cdot B \cdot Co \cdot C_1 \cdot C_L \cdot C_M \tag{1}$$

where,

L = ship length (m)
B = ship breath (m)
Co = wave coefficient :
$\frac{L}{24} + 4.1$ for L < 90 m

C_1 = *hogging*/*sagging* condition as follow :
C_{1H} : $0.19 \cdot Cb$ *hogging*
C_{1S} : $-0.11\ (Cb + 0.7)$ *sagging*

$C_L = \sqrt{\frac{L}{90}}$ for L < 90 m

C_M = distribution factor as follow :
C_{MH} = hogging condition
$2.5 \cdot \frac{X}{L}$ for $\frac{X}{L} < 0.4$
1.0 for $0.4 < \frac{X}{L} < 0.65$
$\frac{1 - \frac{X}{L}}{0.35}$ for $\frac{X}{L} > 0.65$

C_{MS} = sagging condition
$Cv \cdot 2.5 \cdot \frac{X}{L}$ for $\frac{X}{L} < 0.4$
Cv for $0.4 < \frac{X}{L} < 0.65$
$Cv \cdot \frac{\frac{X}{L} \cdot 0.65 \cdot Cv}{1 \cdot 0.65 \cdot Cv}$ for $\frac{X}{L} > 0.65$

Cv = condition with regard to speed of the vessel Vo

By using the BKI load equation for the hogging and sagging conditions, the vertical bending moment values are obtained in Table 2.

Table 2 Vertical wave bending moment Ferry Roro 750 GT

Co	CL	CRw	Cb	C1		Vertical Bending Moment	
				Hogging	Sagging	Hogging (Nmm)	Sagging (Nmm)
6.70	0.85	1.00	0.85	0.16	-0.17	58.10×10^9	-61.42×10^9

2.4 Boundary Condition and Allowable stress

Models are given a constrain to restrain the translational movement of the X direction and the translation of the Y direction. This directional restraint is needed so that the model does not move in the direction of X which allows the model to move back and forth. Meanwhile, the Y direction is restrained so that the model will not trim when performing the calculation process (solve) the ship's strength.

To evaluate the value of the acting stress, the allowable stress value by BKI for material specifications is needed that used in the ship, mild steel grade KI-A, as well as locations that are considered prone to having high stresses such as bottom and deck constructions.

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Allowable stress for bottom construction as follow [7] :

$$\sigma_{LB} = \frac{12.6\sqrt{L}}{k} \qquad \text{for } L < 90 \tag{2}$$

$$\sigma_{LB} = \frac{12.6\sqrt{68}}{1} \qquad k = 1 \text{ (mild steel)}$$

$$\sigma_{LB} = 103.90 \text{ N/mm}^2$$

Allowable stress for deck construction as follow [7] :

$$\sigma_{perm} = \frac{120}{k} \qquad k = 1 \text{ (mild steel)} \tag{3}$$

$$\sigma_{perm} = \frac{120}{1} = 120 \text{ N/mm}^2$$

2.5 Finite Element Method

Finite element analysis is one of numerical technique to running all the complexity of the problem, such as various forms, boundary conditions and loads, those are maintained, but the solution obtained is an estimation. Because of its diversity and flexibility as an analytical tool, it receives a lot of attention in the engineering field. Rapid improvements in computer hardware technology and reduced computer costs have pushed this method because computers are the basic requirement for implementing this method. Using this method, one can analyze several complex structures [8]. Types of structural problems include Stress analysis, Buckling and Vibration analysis.

Stress is defined as the amount of force acting per unit area. There are two types of stress: normal stress and shear stress. Normal stress (σ) is a measure of normal force or axial force per unit area [6]. Mathematically the definition can be written as:

$$\sigma = \frac{F}{A} \tag{4}$$

Defining :

σ = Stress (N/mm^2)
F = Force (N)
A = Sectional Area (mm^2)

The normal stress equation for the three-dimensional plane is as follows :

$$\sigma_x = \frac{E}{(1+v)(1-2v)}\left[\varepsilon_x(1-v)+v(\varepsilon_y+\varepsilon_z)\right] \tag{5}$$

$$\sigma_y = \frac{E}{(1+v)(1-2v)}\left[\varepsilon_y(1-v)+v(\varepsilon_x+\varepsilon_z)\right] \tag{6}$$

$$\sigma_z = \frac{E}{(1+v)(1-2v)}\left[\varepsilon_x(1-v)+v(\varepsilon_x+\varepsilon_y)\right] \tag{7}$$

Finite element analysis software usually has the advantage of being able to produce Von Mises stress values or equivalent stresses, that is the type of stress that results in failure of the material structure formulated by its inventor named Von Mises. To determine the Von Mises stress, the main stress acting on the structure with equation (5-6) is calculated first, after the main stresses are found, the Von Mises stress can be obtained by the equation:

$$\sigma = \left\{\frac{[\sigma_1-\sigma_2]^2+[\sigma_2-\sigma_3]^2+[\sigma_3-\sigma_1]^2}{2}\right\}^{1/2} \tag{8}$$

3. Result and Discussion

The FE model has been implemented. Computer simulation is run under 2 load conditions which are vertical bending moment both hogging and sagging conditions. Reduction in plate thickness is also varied up to 5 variations with an increment of 5% starting from 0%.

3.1 Hogging condition

In this condition, the hull model has been given a vertical bending moment which causes the ship to curve downward. Each thickness variation shows the same structural response, which is experiencing maximum stress at the same place. While the structural stress value looks different for each plate thickness. Stress distribution on the hull structure can be seen in Figure 4.

Tensile stress occurs on the deck plate and a compressive stress occurs on the bottom plate. At 5 thickness variations, it shows the same shape behavior. However, the bending stress values for all thickness variations are different. Bending stress values obtained can be seen in the Table 3.

From the Table 3, increasing in stress occurs at each variation of the plate thickness reduction. However, the obtained stresses from all simulations are still below the allowable stress by the classification, because the construction still has a very good cross-sectional modulus value.

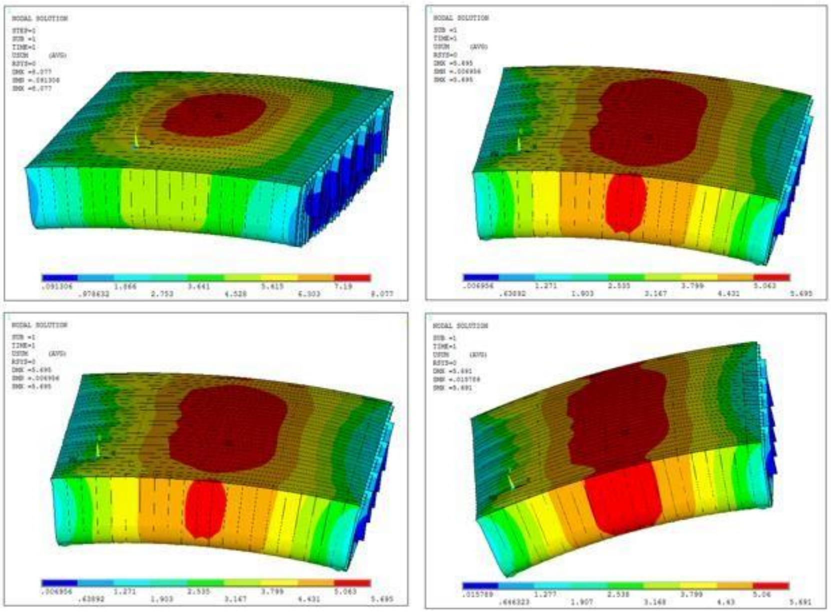

Figure 4. Stress Gradations on Hogging Condition

Table 3. Von Mises Stress in Hogging Condition

No	Percentage of Thickness Plate Reduction (%)	Von Mises Stress	
		Bottom (N/mm^2)	Deck (N/mm^2)
1	0%	82.007	62.939
2	5%	84.340	65.123
3	10%	86.263	69.634
4	15%	88.201	73.383
5	20%	90.142	77.447
6	25%	92.008	79.896

3.2 Sagging condition

In this condition, the ship model is subjected to vertical bending moment due to being in a wave valley. Ships curved upwards, where the bottom plate is subjected to tensile force while on the deck plate being subjeted the compressive force. As for hull responds, it is similar to hogging conditions. Stress number increases in line with the thickness reduction of the hull plate. Stress gradations that occur in the model can be seen in Figure 5.

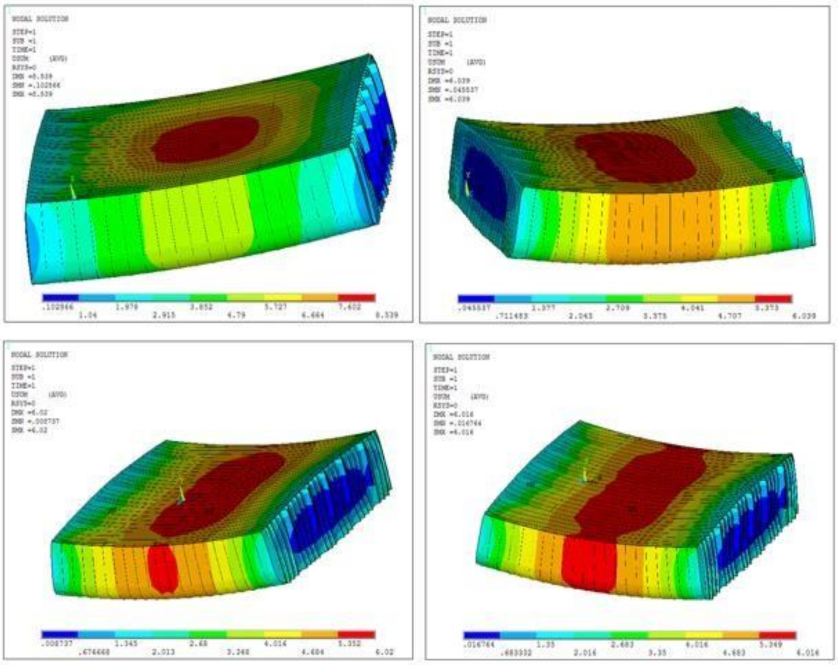

Figure 5. Stress Gradations on Sagging Condition

From numerical experiment simulation result, there is an increase in stress. The greatest stress on each plate thickness variation is on the bottom plate. The stress values for all thickness variations can be seen in Table 4.

Table 4. Von Mises Stress in Sagging Condition

No	Percentage of Thickness Plate Reduction (%)	Von Mises Stress	
		Bottom (N/mm^2)	Deck (N/mm^2)
1	0%	86.694	66.537
2	5%	89.458	69.728
3	10%	91.194	73.615
4	15%	94.170	77.578
5	20%	96.930	81.341
6	25%	98.666	85.104

From the two simulations, the obtained result is the value of the hull strength decreased for each thickness reduction of the hull plate. The effect caused by the thickness reduction is a decrease in section modulus of the ship, it decreases due to the reduced cross-section inertia value of the hull. In the equation for obtaining cross-section inertia, it is greatly influenced by the structure dimension.

The two simulations show that the stress value is still below the allowable stress value of BKI as seen in Figure 6. This means that the ship is still safe for operation, even though it has decreased plate thickness by up to 25%. This is due to the class rules using a high safety factor in determining the size of the construction.

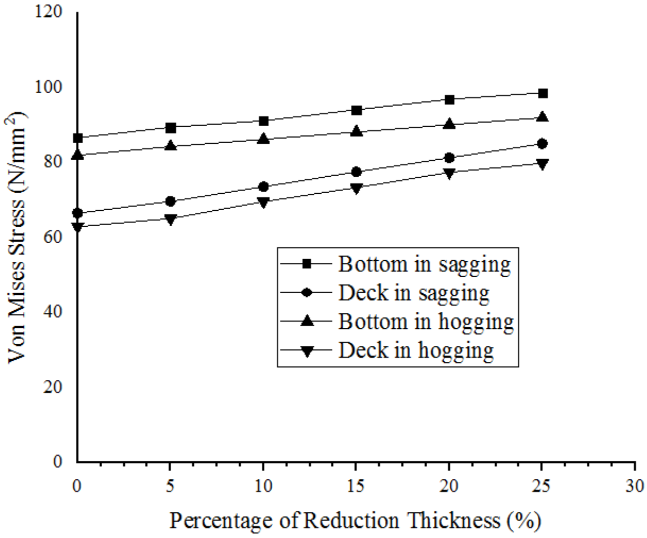

Figure 6. Von Mises Stress of All Conditions

4. Conclusion

The numerical simulation has been conducted using ANSYS 15 software and analysed by using Finite Element Method. Stress values have been obtained for for each increment of the plate thickness reduction of the hull both in the hogging and sagging condition. In the former condition, the stress value increases both in the deck and the bottom which is an average of 2.27 % and 4.65% respectivelly. Meanwhile, it increases by an average 2.55% and 4.80% in the later condition. Based on the obtained results, it is necessary to verify the useg of optimum construction size in the hull. After reducing the plate thickness, the hull can still withstand the vertical bending moment. So, in the future, a study is needed to reduce safety factors in order to obtain an estimation steel material weight which is lighter and technically feasible.

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