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Procedia Structural Integrity 27 (2020) 46–53

Structural Integrity Procedia

www.elsevier.com/locate/procedia

6th International Conference on Industrial, Mechanical, Electrical and Chemical Engineering (ICIMECE 2020)

Finite Element Based Analysis of Steering Construction System of ORCA Class Fisheries Inspection Ship

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Abstract

The fisheries inspection class is the ship which featured with high maneuver and speed. The rudder construction system must be strong enough to withstand the external pressure due to the maneuver of the ship. Therefore, material selection must be proper. Before selecting the material, the external pressure of steering construction must be examined and performs the Finite Element (FE) analysis. In this paper, the variable for FE analysis was focused on the slope of the rudder. It consisted of 0°, 10°, 20°, and 35°. The slope analysis was performed numerically by Computational Fluid Dynamics (CFD) software. Then, the external pressure can be generated based on the CFD analysis results, which can be used as an input force in Finite Element analysis. Finally, the results were distinguished from the von-Mises stress, deflection, and safety factor. Each component of the steering construction system was examined in which the component consisted of the rudder, rudder stock, flange, bolts, and nuts. It was found that the flange component had a more significant value of stress and a smaller value of safety factor.

Keywords: Fisheries inspection ship; Rudder construction; Stress analysis; Finite Element Analysis

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2452-3216
10.1016/j.prostr.2020.07.007

1. Introduction

Indonesia is an island country with an ocean area of 3.273.810 km^2. By having an ocean area that is wider than the land area, making the Indonesian maritime sector a vital sector that can be developed in supporting national economic growth. In 2016, the ministry of marine affairs and fisheries was ordering four fisheries inspection ship into the fleet of Indonesia Fisheries Inspection Ship System or in Indonesian abbreviation is SKIPI. The fleet composition is an Orca class with 60 meters of length. This Orca class ship will strengthen law enforcement in the Indonesian sea. Fishery inspection ship must have excellent maneuverability when operating because this ship functions to hunt ships that do illegal fishing. To get a good maneuver, one of the influential factors is the material strength of the steering construction system. Thus, it is required to analyze the strength of construction regarding its external pressure.

Tsevdou et al. were brought an investigation of rudder horns of bulk carriers and oil tankers. The structural integrity analysis was based on FE method. The result of the structural analysis was following the IACS requirements (Tsevdou et al., 2020). Sometimes, the rudder construction could cause failure due to poor fabrication, such as during the weld joint. It can be weakening the part connection. Gunarathna was investigated weld joint failure of the rudder stock connection. The weld joint was declined due to the formation of intermetallic phases, carbide precipitation, porosities, and hot cracks in HAZ. The material of weld contains 4% to 12% ferrite (Gunarathna, 2016). Several joints composed the rudder constructions. The mechanical joint also to be concerned in the analysis of rudder construction. Nubly et al. investigated the strength analysis of propeller shaft on certain fisheries inspection boat. The finite element method was used, which the idealized model consisted of several mechanical joints, e.g., bolts, nuts, flange connections, and key. The investigation also included the friction coefficient in each part of the numerical model. Therefore, the failure of a specific component can be easily detected (Nubly et al., 2017). The force that affected the rudder construction is mainly from the interaction of the structure and fluid. Thus, before performing the strength analysis in Finite Element, the force should be obtained from the computational fluid dynamics (CFD) analysis. In advance, it can be combined in coupled fluid structural analysis (Turnock et al., 2000).

In this study, the investigation was focused on the maximum stress and the safety factor of the rudder construction. The external pressure of the rudder blade was obtained from the CFD analysis with several rudder angles of attack. Finally, the critical part of rudder construction can be detected in finite element analysis.

2. Rudder model and material

2.1. Rudder construction

The rudder construction is a critical role in the movement of a ship. The function of the rudder is to control the course of the ship or to maneuver. Because the rudder has an essential role in a ship, the rudder must meet a safety standard for a voyage. The steering system includes all parts of the equipment needed to steer the ship, from the steering, shaft, and propulsion installation to the wheel itself. The Orca-class boat was installed the full spade type rudder. The full spade rudders are actively used in high-speed vessels. It purposed to alleviate cavitation problems (Shin et al., 2019). The 3D model of the rudder construction used in this study can be shown in Fig 1.

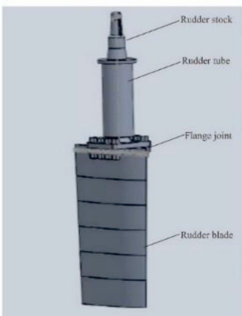


Fig. 1. The 3D model of full spade rudder construction.

2.2. Materials in rudder construction

The various materials are used in this rudder construction. The material consisted of three groups. The first material group for the rudder blade and the flange were used KI A36, which equivalent to ASTM A36 common structural steel. The "KI" abbreviation was implemented for the ship classification society in Indonesia. The second group for rudder stock used the SS 400, and the last groups for bolt components were used AISI 316 stainless steel. The material properties are shown in Table 1.

Table 1. The material properties of the components.

Steel code	Yield strength (MPa)	Tensile strength (MPa)	Poisson's ratio	References
KI A36	235	520	0.26	BKI, 2019
SS 400	245	510	0.29	Material grades, 2020
AISI 316	205	515	0.30	Upmet, 2020

3. External pressure calculation

The external pressure was affected by the rudder due to the fluid flow, which passes through the rudder blade. In this investigation, the CFD code was performed to detect the external pressure of the rudder blade. The angle of attack (AOA) was used in the variable. The AOA was distinguished of 0°, 10°, 20°, and 35°. In the CFD analysis, the ship velocity was assumed as 24 knots where this velocity is the maximum service velocity of the ORCA class boat. The assumption was decided due to knowing how strong the rudder construction in extreme conditions. In the CFD analysis, the wall force feature was implemented to detect external pressure. Then, the rudder blade model was split into 12 sections. The blade was split depending on the location of the welded joints of the rudder blade. The external pressure of each rudder blade section was shown in Table 2. Then, the external pressure data can be used in the finite element analysis.

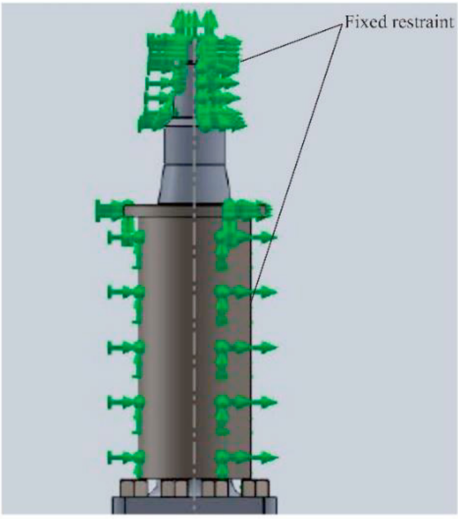
Table 2. Results of the external pressure of the rudder blade.

Rudder blade sections	Area of rudder blade sections (mm^2)	External pressure of each slope (MPa)			
		0°	10°	20°	35°
1	380	-14.6845	-5.18597	5.37155	17.4958
2	380	-14.7174	-36.5168	-56.6536	-91.1625
3	360	-17.7971	-2.0745	13.9008	37.4429
4	360	-17.8096	-41.1395	-51.7738	-86.6162
5	350	-18.7495	-989.678	15.4255	42.5057
6	350	-18.8513	-44.1391	-51.4743	-80.3054
7	340	-18.7274	-0.59678	15.4138	42.994
8	340	-18.663	-44.0913	-51.5062	-77.4917
9	340	-17.5903	-1.20801	14.2807	38.733
10	340	-17.5691	-41.6334	-51.9875	-86.732
11	360	-14.5831	-4.1638	5.25986	18.9844
12	360	-14.663	-37.7454	-58.1603	-91.7239

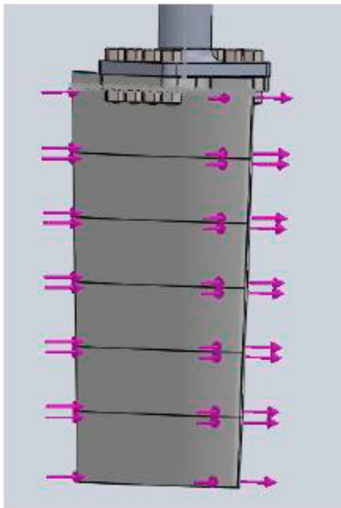
4. Finite element analysis

The procedure of finite element analysis consisted of three steps. Due to the rudder construction was composed of several components. Thus, the contact of components should be defined. The weld joints in the rudder blade shell were assumed to be bounded in this analysis. It was due to the finite element was focused on the mechanical joints only. Then, the contact between the flange, rudder stock, and rudder tube was defined as unbounded. The friction coefficient between flange and rudder stock is 0.5, and the rudder stock and stern tube are 0.2. The rudder tube also lubricated with the lube oil. Thus, it has a smaller friction coefficient.

The fixed restraint was implemented for the finite element model. The constraint was located on the upper tip of the rudder stock, which was connected to the flange of the steering gear. Also, the restraint was added on the rudder tube. It can retain the translation movement of the rudder stock. Thus, the rudder stock can only move in the rotational motion. The restraint location was shown in Fig 2(a).



(a)



(b)

Fig. 2. (a) The location of restraint in the rudder tube and rudder stock tip; and (b) The load location in the rudder blade model.

The load condition of the rudder blade is an external pressure in MPa. The direction of the load was headed to the side of the rudder blade. This condition occurs due to the slope of the rudder blade. The model was not rotated in the finite element model. It can be represented by the various load in each slope of the rudder blade. The load location of the rudder blade is illustrated in Fig 2(b).

5. Results and discussions

The main goal of the finite element analysis is to obtain the maximum stress, displacement, and safety factor of each component in several slope condition of the rudder construction. The results can be obtained in the post-processing interface of the finite element software. Fig. 3 shows the maximum stress of the rudder component in 0° slope condition. In the state of the slope 0°, it is known that the steering wheel experiences maximum stress of 67.12 MPa (see Fig. 3a). This is caused by seawater pressure at the speed of the shipping service at 24 knots. On the steering flange affected maximum stress of 22.10 MPa (see Fig. 3b), then the bolt touched maximum stress of 2.74 MPa (see Fig. 3c) and on the rudder stock changed maximum stress of 7.19 MPa (see Fig. 3d) due to continuing force which obtained from external pressure at a ship speed of 24 knots. For resultant displacement, at 0° steering condition, it is known that the steering wheel has a maximum displacement of 1.76 mm. In the steering, flange displaced a maximum of 0.13 mm, then the bolt deformed by 0.00563 mm, and the rudder stock distorted by 0.0039 mm.

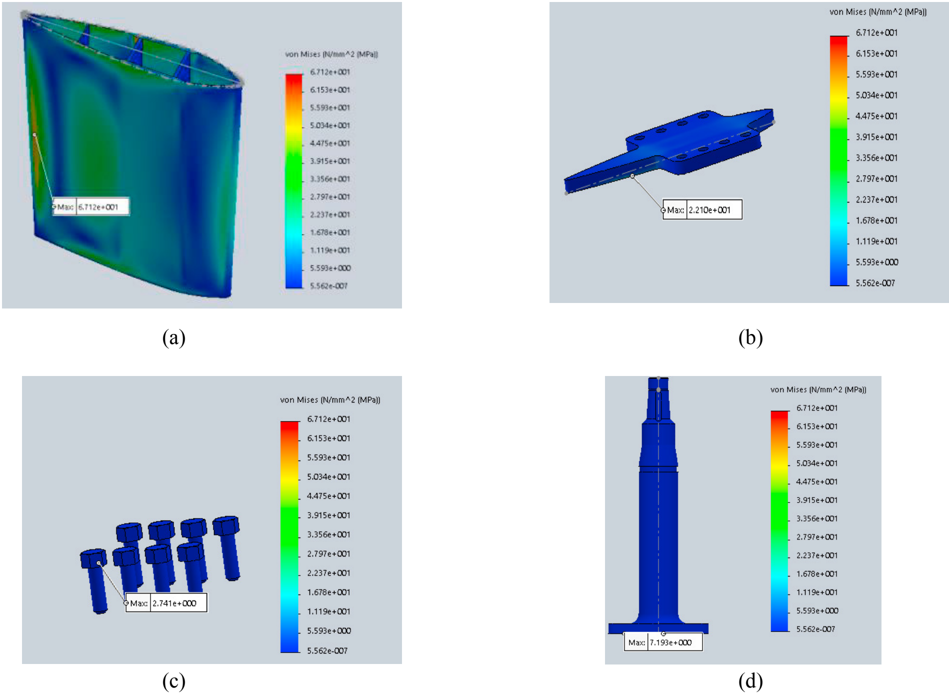


Fig. 3. The stress of the 0º slope.

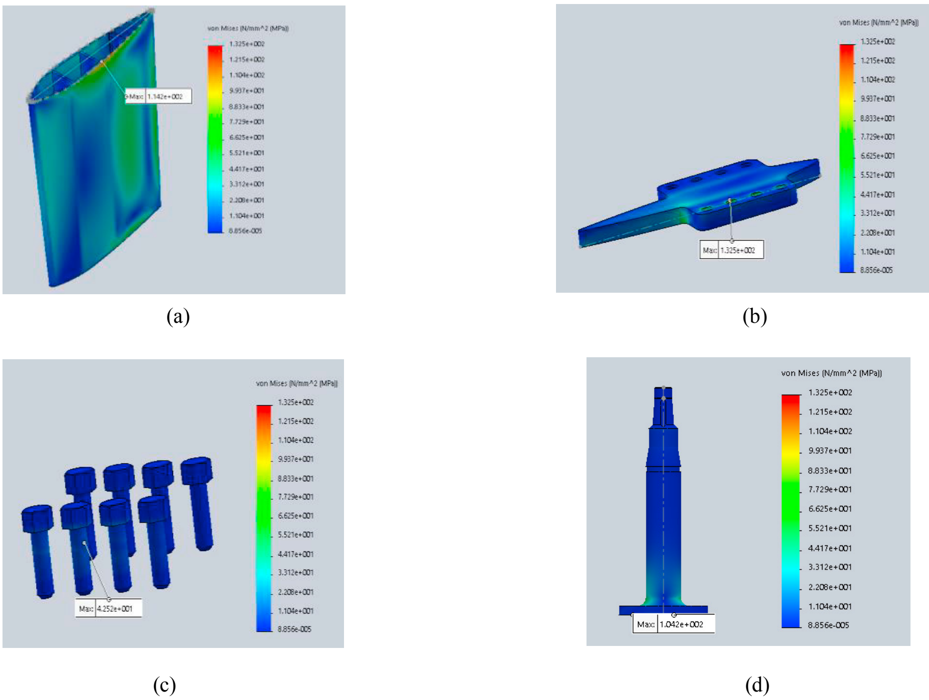
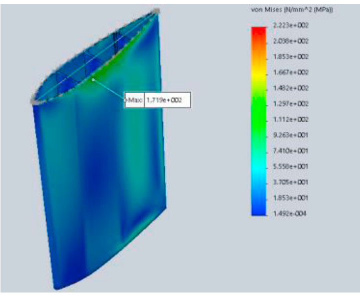


Fig. 4. The stress of the 10º slope.



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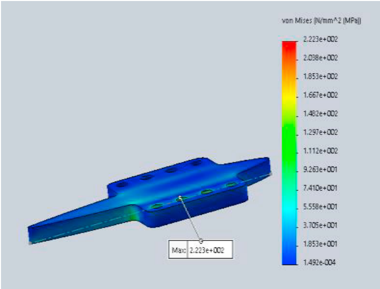

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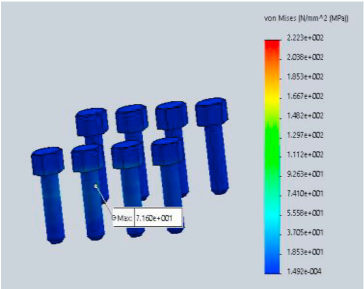

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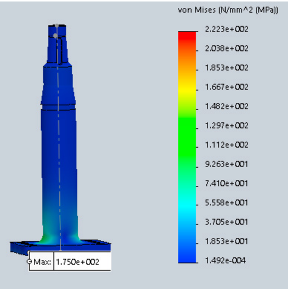
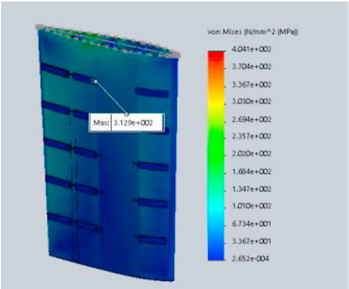


(d)

Fig. 5. The stress of the 20º slope.



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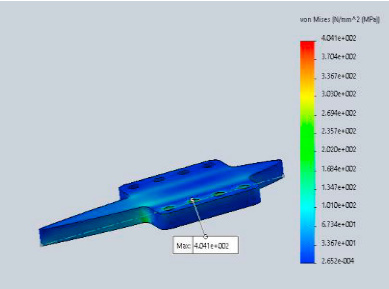

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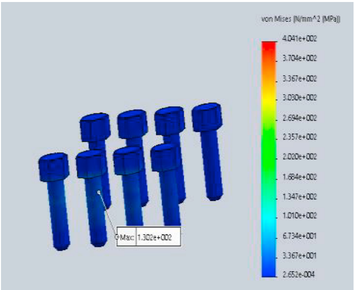

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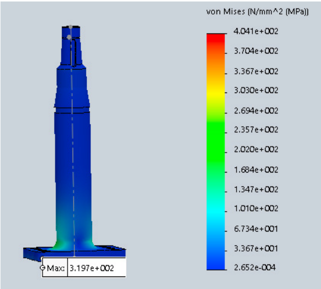
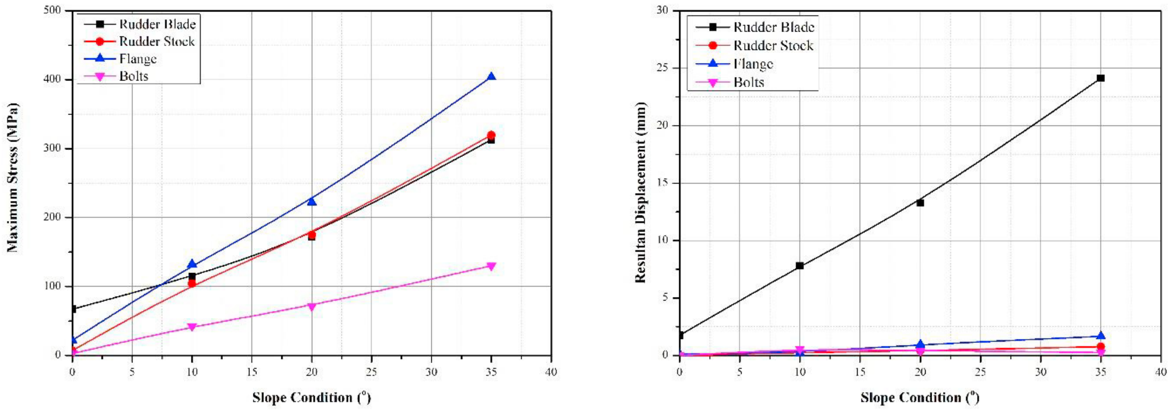


(d)

Fig. 6. The stress of the 35º slope.

In the slope condition of 10°, it is shown that the rudder blade and flange have 114.21 MPa in (see Fig. 4a) and 132.5 MPa in (see Fig. 4b), respectively. The maximum stress of bolts and the rudder stock have 45.52 MPa and 104.15 MPa, respectively. The resultant displacement of the rudder blade, flange, bolts, and rudder stock has 7.81 mm, 0.58 mm, 0.25 mm, and 0.24 mm, respectively. Fig. 4 shows the overall maximum stress in the 10° slope condition. The maximum stress of 20° slope condition was shown in Fig. 5, it is shown that the rudder blade and flange have 171.94 MPa in (see Fig. 5a) and 222.30 MPa in (see Fig. 5b), respectively. The maximum stress of bolts and the rudder stock have 71.60 MPa and 175.01 MPa, respectively. The resultant displacement of the rudder blade, flange, bolts, and rudder stock has 13.26 mm, 0.95 mm, 0.43 mm, and 0.42 mm, respectively. The maximum stress of the 35° slope condition was shown in Fig. 6. It is shown that the rudder blade and flange have 312.89 MPa in (see Fig. 6a) and 404.06 MPa in (see Fig. 6b), respectively. The maximum stress of bolts and the rudder stock have 130.17 MPa and 319.70 MPa, respectively. The resultant displacement of the rudder blade, flange, bolts, and rudder stock has 24.13 mm, 1.66 mm, 0.25 mm, and 0.76 mm, respectively. The maximum stress and displacement can be concluded in the curve of maximum stress and resultant displacement. Figs. 7a and b show the relation curve of variables and the slope condition.



(a) (b)

Fig. 7. (a) The relation of maximum stress and slope condition; and (b) The association of resultant displacement and slope condition.

The safety factor can be calculated with the ratio of allowable stress against the maximum stress from the finite element results. The allowable stress is based on the "Rules for Hull Vol. II, Section 14" of Biro Klasifikasi Indonesia, where the allowable stress is 120 MPa (BKI, 2014). The safety factor cannot be smaller than 1. Thus, some of the components have an unstable condition. Fig. 8 shows the safety factor of each component in various slope conditions.

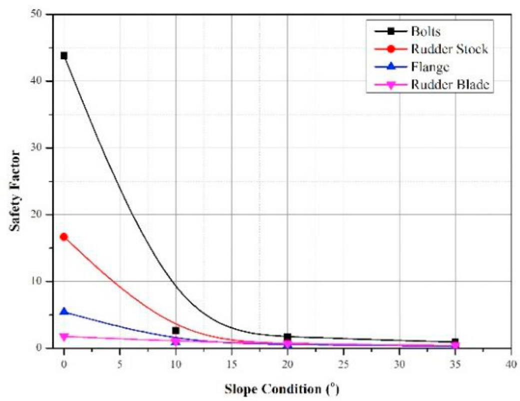


Fig. 8. The relation of safety factor and slope condition.

6. Concluding remarks

Based on the finite element analysis, the investigation of rudder construction structural strength can be concluded as follows:

1. The slope condition of 35º has more significant stress in each component. Thus, the slope condition is directly proportional to stress.
2. The smallest safety factor is in the flange with 35° of slope condition. It occurred due to the flange was experienced the extreme torque in this condition.
3. Based on the investigation, several components failed to comply with the BKI recommendation due to the safety factor is below 1. Notably, in the 35° of slope condition.

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