Hull Strength Investigation of Traditional Boat "Sandeq" Using Numerical Experiment

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ABSTRACT

Sandeq is an Indonesian traditional boat that is built instead of applying principal spiral design and technical calculation in its design and construction. Its construction relies on the inherited skills of the builders. However, to ensure that the strength of the ship is less or more, a scientific approach is needed. If the ship has less strength, it is necessary to provide additional construction. If the ship has excessive strength, it is necessary to optimize the size of the construction that is economically feasible. This study aims to investigate the structural strength of the boat with numerical experiments by computer software that applying the finite element method (FEM). Longitudinal and transversal hull strength will be examined for four Sandeg models. The computational model of the boat hull is designed and run with varieties of hull lengths using the software. The simulation results show that the obtained longitudinal and transversal stresses are less than the allowable stress of the material based on the classification rules. In the transversal strength analysis, the ratio of working stress to material stress are 6,37%, 7,20%, and 5,98% on the sandeq A, B, and C respectively. As for longitudinal stress in hogging condition, the ratio are 2,77% 3,35%, 0,93%, and 0,72% on the sandeq A, B, C, and D respectively. for sagging condition, the ratio was 2,11%, 2,49%, 0,52%, and 0,69%.

1. INTRODUCTION

A variety of different types of wooden ship can be found in Indonesia. the ships vary in terms of their shape and usage, for example for cargo transportation, fishing, and tourism boat. One of the wooden ships that can be found in Indonesia is Sandeq located in Sulawesi Island. The material construction of the boat is woods and the traditional method is still applied in its construction in which spiral design which is commonly adopted in the design of steel, aluminum dan FRP ships is avoided in this method. Estimation of construction dimension is performed based on experiences for generations. However, hull strength evaluation should be taken into account after determining the dimension.

Studies on ship strength and wooden boats have been performed by many researchers such as, Analysis of wooden ship construction technique according to BKI rules with structural modeling approached (Aditya et al, 2020). Ship modeling has been carried out using is finite element with multiple structure size option. The result showed that significantly stronger strength value than BKI limit standart. In other researched, wooden joint analysis on the traditional wooden ship has been carried out by Yohanes et al, 2016. In that study, researchers used the FEM method to determine the strength of the connection on wooden ship beams and connecting bolts. The results show a safe stress on the wooden beam structure. In other case, wooden warship in 17th Century has been modeled as a finite element by Afshar et al, 2021. The results showed a high ratio of structural shear stress and tangential stress.

A sandeq has characteristics that differentiate it from many other outrigger boats. in addition to having a unique form with length ranging between 7 – 16 meters and width ranging 0,5 – 1 meter, it is installed bamboo outriggers on the port side and starboard side as a stabilizer, it relies on blowing wind that is captured by triangle sail, it is able to accelerate with a speed of 15 – 20 Knots or 30 – 40 Km/h (Syamsurijal, 2011). Overall, A sandeq building process is similar to any other boat construction process with exception of some parts, it is because sandeq's structure and shape having different and unique characteristics (Alimuddin, 2005) as shown in Figure 1. At glance, Sandeq is light, fast, and strong. However, by looking into it from a different perspective, the hull strength of sandeq should be examined further to ensure sandeq users.

The structure of wood is quite complex with respect to its material properties and structural response, therefore it needs to be simulated using numerical methods (Kanopka et al, 2016). Building structures with wood materials need to be analyzed to provide support for the development and strengthening of construction, because wood has relatively short-term strength.

Figure 1. Traditional Boat 'Sandeq'

In this regard, the objective of the present study is to perform an investigation on the hull strength of sandeq which is built with the traditional method. The Longitudinal and transversal hull strength of the boat will be examined. The numerical experiment will be used with computer software that applies the finite element method (FEM). The computation model of sandeq hull will be made based on construction data that obtained from filed survey. The hull model comprises four length variations (LOA). The midship part of sandeq hull will be modeled with three frame spaces. This simplification of the model is carried out to facilitate the computer machine solving mechanical problems in the simulation.

2. METHODS

2.1. Sandeq Boat

four main dimension variations of sandeq with simple construction consisting of bottom plate, side plate, deck plate, frame, deck beam, and level will be examined in the present study. The hull form of sandeq can be seen in Figure 2, and Table 1 shows the main dimension of sandeq which is the objects in the present study. There are 4 main dimension of sandeq to simulated. This size was chosen because the sandeq size is commonly used by fishermen.

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Table 1. Main Dimension of Sandeq

No	Item	Sandeq A (m)	Sandeq B (m)	Sandeq C (m)	Sandeq D (m)
1	Length overall (LOA)	14.2	12.29	9.1	7.1
2	Beam (B)	0.57	0.68	0.65	0.55
3	Depth (H)	0.63	0.51	0.63	0.48
4	Draft (T)	0.32	0.35	0.5	0.4

Palapi wood is used on the sandeq boat in the present study. PKPI classifies the wood into one of the Meranti wood subspecies. The material properties of Meranti are as follows (Yohanes, 2016).

Young Modulus (E_x) : 13900,00 N/mm^2
Young Modulus (E_y) : 9266,66 N/mm^{2V}
Young Modulus (E_z) : 772,22 N/mm^2
Poison Ratio ($\surd_x$) : 0,33
Poison Ratio ($\surd_y$) : 0,33
Poison Ratio ($\surd_z$) : 0,33
Shear Modulus (xy) : 1379,00 N/mm^2
Shear Modulus (xy) : 114,91 N/mm^2
Shear Modulus (xy) : 91,33 N/mm^2

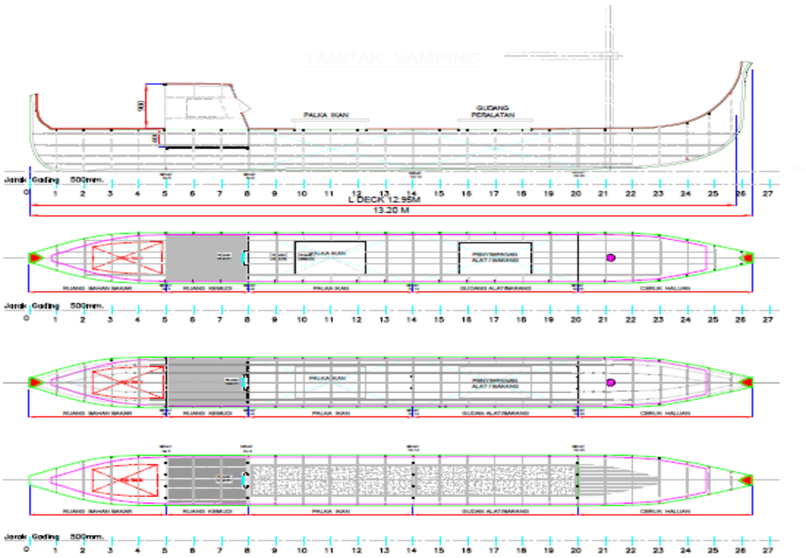

Figure 2. Sandeq Construction

2.2. Hull Modeling and Load

The FE model of sandeq hull will be designed then it will be subjected to loads with boundary conditions. The hull form and geometry that is inputted is based on measurement data and then data is processed to produce lines plan dan midship section designs. In the present study, the hull modeling uses solid elements with orthotropic material types. As for meshing size. It is adjusted to the capabilities of the computer hardware. FE model that has been run in the present study can be seen in Figure 3.

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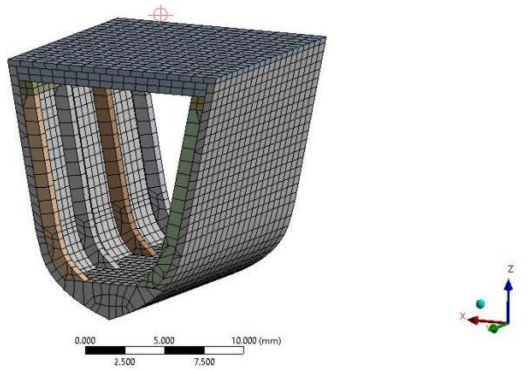

Figure 3. FE Model and Mesh

In the case of loading, it divides into two parts. First, transverse loading comprises of bottom loads, side loads, deck loads. And second, longitudinal loading consisting of vertical bending moment in hogging and sagging conditions. To determine transversal loads. The following formulas are applied:

Loads calculation on shell bottom (BKI, 2013)

$$PdBS = 3.29\ L - 1.41 \quad (1)$$

Shell Side (BKI, 2013)

$$PdSS = 2.63\ L - 2.35 \quad (2)$$

Main Deck (BKI, 2013)

$$PdD = 0.26\ L + 8.24 \quad (3)$$

Where,

L = $\frac{LWL+LOA}{2}$

L = L scantling (m)

LWL = Length of Waterline (m)

LOA = Length overall (m)

For longitudinal loads. The following formula is used (BKI, 2021) :

$$M_{WV} = L^2.B.Co.C_1.C_L.C_M \ \text{kN.m} \quad (4)$$

Where,

L = ship length (m)

B = Beam (m)

Co = wave coefficient

C_1 = sagging or hogging condition

C_1H = 0.19 Cb for hogging condition

C_1S = -0.11 (Cb +0.7) for sagging condition

C_L = length coefficient

C_M = distribution factor

The value of transversal loads for each sandeq dimensions can be seen on Table 3. and longitudinal loads are shown in Tabel 4.

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Table 3. Transversal Loads

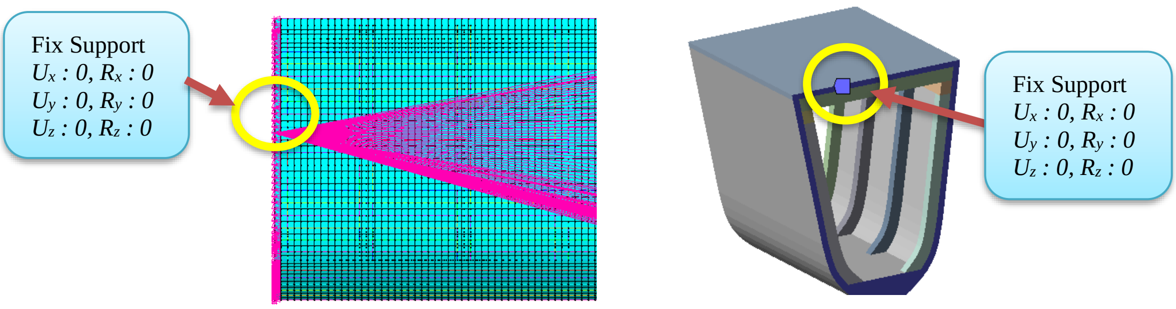
Hull Area	Transversal Loading (kN)			
	***Sandeq* A**	***Sandeq* B**	***Sandeq* C**	***Sandeq* D**
Shell Bottom (< 0.4 L ÷ aft)	0.0439	0.0398	0.0279	0.0213
Shell Bottom (≥ 0.4 L ÷ fore)	0.0348	0.0316	0.0221	0.0169
Shell Side (< 0.4 L ÷ aft)	0.0339	0.0306	0.0211	0.0158
Shell Side (≥ 0.4 L ÷ fore)	0.0254	0.0229	0.0154	0.0113
Main Deck	0.0118	0.0115	0.0106	0.0100

Table 4. Vertical Bending Moment

Condition	***Sandeq* A**	***Sandeq* B**	***Sandeq* C**	***Sandeq* D**
Hogging (N.mm)	1,348 x 10^7	1,190 x 10^7	4,625 x 10^6	1,946 x 10^6
Sagging (N.mm)	-1,765 x 10^7	-1,603 x 10^7	-6,208 x 10^6	-2,704 x 10^6

2.3. Boundary Condition

To observe the maximum response of the hull optimally, fixed support is adopted in the present study. The pedestal is given to both ends of the model when analyzing the transversal strength. For longitudinal strength, multi-point constraints (MPC) are used by controlling all node points at the end of the model to a central point located on the neutral axis of the hull section. For this case, two MPC points are required. In this model, one of the points at the end of the model (AP or FP) will be given fixed support and the other points are only controlled in Y rotation. For the working load, it will be given at the point which is controlled in rotation Y. Another load point will be given a vertical bending moment to determine the response of the ship's structure. The configuration of the supports can be seen in Figure 4.



(a) Boundary Condition of Longitudinal Strength (b) Boundary Condition of Transversal Strength

Figure 4. Controlling on FE Model

2.4. Finite Element Method (FEM)

FEM is a numerical modelling to solve differential equation that describe many engineering problems (Kim, 2008) and mathematical problems (Susantio, 2004). Typical problems in engineering and mathematic, and physics that can be solved using FEM include structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potentials (Logan, 2007). The core process of the method is to divide a complex problem into smaller parts or elements from which simpler solutions can be easily derived. The solution of each element when combined will be a solution to the problem as a whole. The FEM constitutive equation for structural stress in the form of a matrix formed from the derivatives of various equations is as follows:

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$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \underbrace{\frac{E}{1-v^2}\begin{bmatrix} 1 & v & 0 \\ v & 1 & 0 \\ 0 & 0 & \frac{1-v}{2} \end{bmatrix}}_{[C]} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} \tag{5}$$

To be shorten: $\{\sigma\} = [c]_\sigma\{\varepsilon\}$ (6)

Where: $\{\sigma\}$ = Stress vector, $\{\varepsilon\}$ = Strain vector, $[c]_\sigma$= Constitutive matrix for Plane Stress

3. RESULT AND DISCUSSION

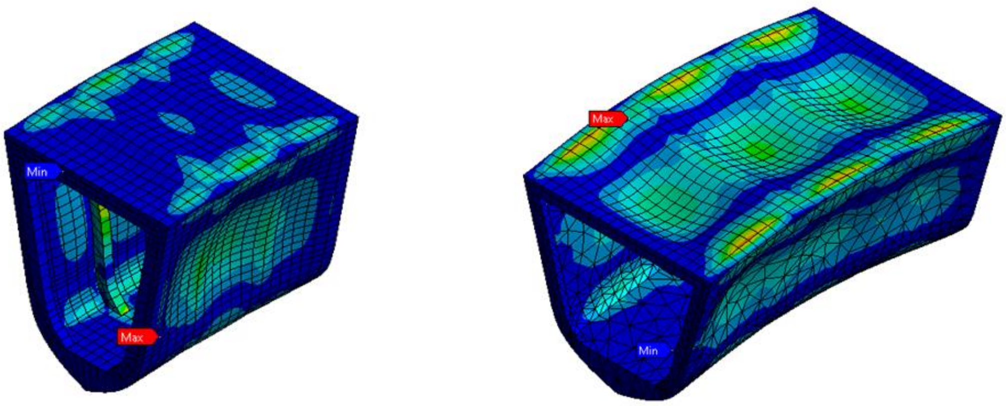
In the most cases, Ship strength is examined by stress and deformation acting on a structure when subjecting to loads. The working stress and deformation of the sandeq's hull are described as follows:

3.1. Transversal Strength

After performing a computer simulation, the stress and deformation of four sandeq models with transversal loads could be determined as shown in Table 4, and the stress distribution of the models can be seen in figure 5.

Table 4. The working Stress on the sandeg subjected to transverse loads

No	Sandeq model	Deformation (mm)	Stress (N/mm^2)
1	Sandeq A	0.092	8,22
2	Sandeq B	0.167	9,39
3	Sandeq C	0.379	7,72
4	Sandeq D	0.164	3,34



(a) Sandeq A (b) Sandeq B

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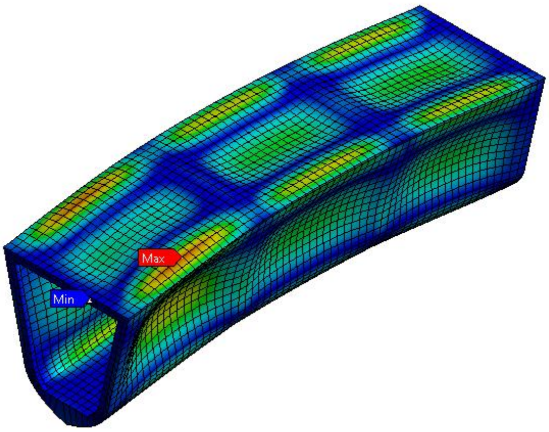
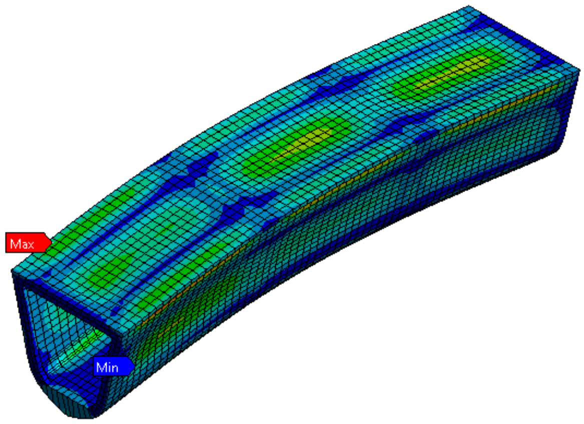


(c) Sandeq C



(d) Sandeq D

Figure 5. Stress distribution of Sandeg Hull

It can be seen that different loads were working on the hull as consequence of the main dimension of the boat. However, the response of the structure against the loads was similar in general. Based on simulation results of the transversal strength, each model had a variety of stress values. Sandeq B experienced the highest stress with a value of 9,39 N/mm2. In contrast, with a value of 3,34 N/mm2 Sandeq D had the lowest stress. Having a small main dimension and similar dimension of construction with the other sandeqs, as a result, Sandeq D had a high section modulus to reduce the stress. In case of Sandeq B, it had a bigger main dimension, and consequently experienced loads larger than Sandeq C and D. Still, the construction dimension of Sandeq B was not as big as Sandeq A. Regarding deformation, small value was experienced by all Sandeg, thus their hull had an insignificant change in shape.

In general, all sandeq had a proper construction strength (safe). The working stress is significantly below the ultimate strength of meranti wood recommended by Biro Klasifikasi Indonesia which is 129 N/mm2. As a result, the hull construction of the sandeqs is very feasible in case of transversal strength. The same result also occur in the study conducted by Aditya et al (2020). The stress distribution of the sandeq models is shown in Figure 6.

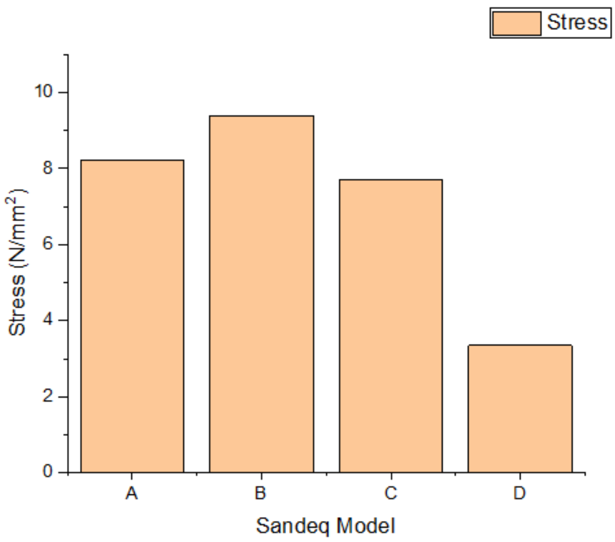


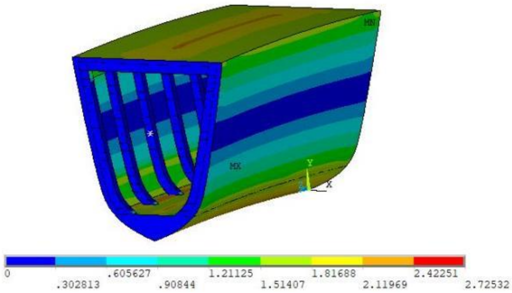
Figure 6. Transversal Strength on Sandeq Models

3.2. Longitudinal Strength

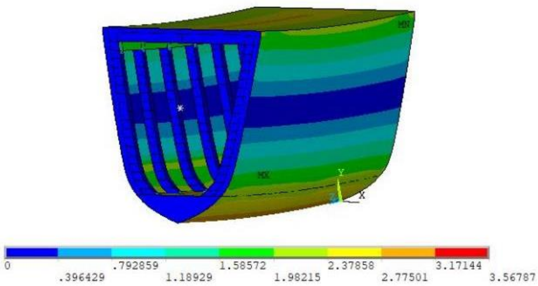
The obtained working stress and deformation of longitudinal strength for all sandeqs is shown in Table 5, and the stress distribution can be seen in Figure 7.

Table 5. Stress and Deformation of Sandeg Models.

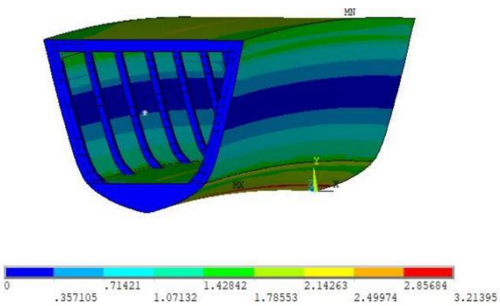
Sandeq Models	**Deformation (mm)**		**Stress (N/mm^2)**	
	Hogging	**Sagging**	**Hogging**	**Sagging**
Sandeq A	0.002	0.001	3,568	2,725
Sandeq B	0.002	0.002	4,328	3,214
Sandeq C	0.002	0.002	1,191	0,667
Sandeq D	0.004	0.003	0,931	0,887



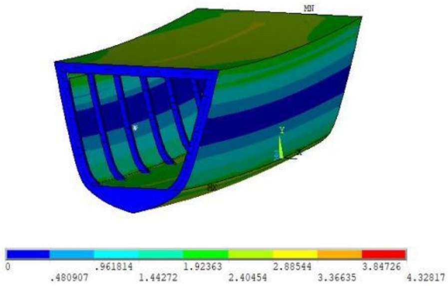
(a) Sandeq A (Hogging)



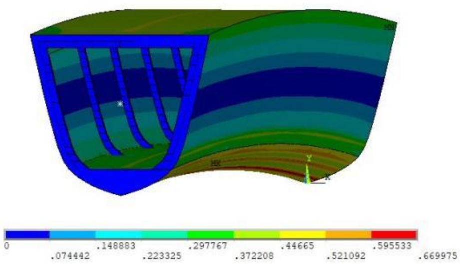
(a) Sandeq A (Sagging)



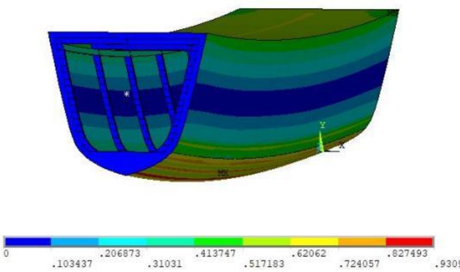
(b) Sandeq B (Hogging)



(b) Sandeq B (Sagging)



(c) Sandeq C (Hogging)



(c) Sandeq C (Sagging)

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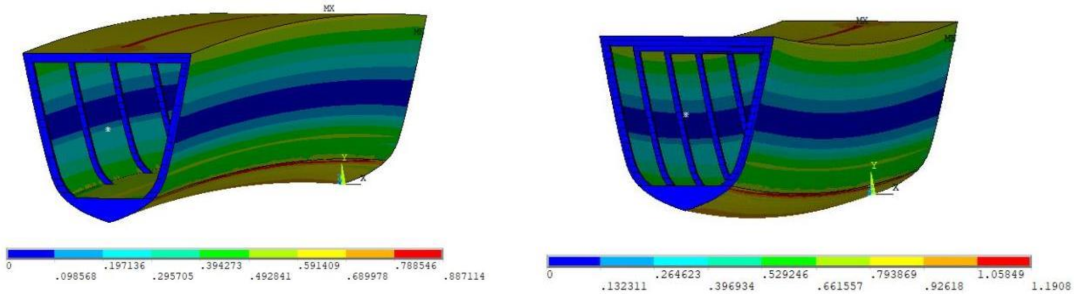

(d) Sandeq D (Hogging) (d) Sandeq D (Sagging)

Figure 7. Stress Distribution of Sandeq Model (A-D)

Based on Figure 7, It shows that the highest stress was experienced sandeq B on the hogging condition with a value of 4,328 N/mm2. In sagging condition, Sandeq B subjected to the highest stress which is 3,214 N/mm2. Contrary, the lowest working stress both conditions were experienced Sandeq D and C with values of 0,931 N/mm2 and 0,667 N/mm2 respectively.

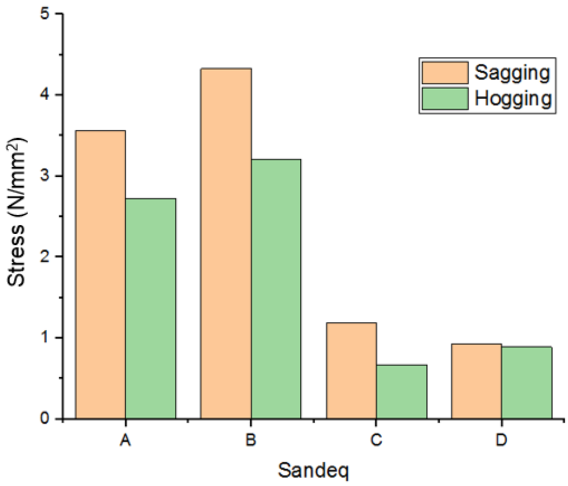

Figure 8. Stress Distribution of Sandeq Hull due to Longitudinal Loads

The simulation results reveals that the stress acting on all variation of sandeq models has a low category. The stress is still below material stress based on BKI Rules. The variation of stress value for each Sandeq length was resulted by difference section modulus. Furthermore, the center gravity location of the cross-section for each sandeq dimension variation greatly influenced on generating the maximum stress of sandeq hull. On the whole, all four sandeg models that have been examined in the present study is feasible to be optimized their dimension of hull constructions. This optimizing will effect on an efficiency of material construction usage and reducing ship building cost from material aspect. As an initial data, the level of working stress value differences for each sandeq variation can be seen in Figure 8.

4. CONCLUSION

Numeric simulation has been performed on the hull models of traditional boat 'Sandeq' using finite element analysis. The numerical simulation that carried out to obtain longitudinal and transversal hull strength of the traditional boat. The results of the simulation based on the inputted loads with BKI Rules are as follows:

1. The transversal strength of the sandeq hull was expressed with the working stress after subjected to transverse loads. The ratio of maximum working stress to allowable stress material for each sandeq length variation is 6,37%, 7,20%, 5,98%, and 2,59% for sandeq A,

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B, C, and D respectively. This result reveals that the hull construction of sandeq could be optimized as the working stress of transversal strength is still categorized small.

2. The longitudinal strength for each sandeg length variation depicts the working stress is smaller than the material strength both hogging and sagging conditions. The ratio of the working stress to the material stress for each condition is expressed as follows; 2,77% (sandeq A), 3,35% (sandeq B), 0,93% (sandeq C) dan 0,72% (sandeq D) for hogging condition. and 2,11% (sandeq A), 2,49% (sandeq B), 0,52% (sandeq C) dan 0,69% (sandeq D) for sagging condition.

It can be concluded from the above results that it highly recommended to proceed this study by performing the optimization dimension construction of sandeq hull. This optimization aims to perform an efficiency of sandeg hull usage with keeping on paying attention to the technical feasibility of the boat.

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