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INVESTIGATION OF STRUCTURAL RESPONSE OF THE CATAMARAN LIVESTOCK CARRIER IN INDONESIA WATERWAYS ENVIRONMENT

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***Abstract*— The investigation of the structural response of the proposed design of the catamaran livestock have been presented. The main aspects of the structural design evaluation of the catamaran livestock carrier have been made. The catamaran structure is characterized by the twin-hull form that offers larger deck areas compare with the monohull structure. The finite element (FE) model has been developed by generating the model of the parallel middle body part of the vessel. Stillwater and wave load condition (sagging and hogging) have been considered for the evaluation to assess the capability of hull structure to withstand the hydrostatic load and the hull girder bending load in the Indonesia waterways environment. The structure strength analysis has been carried out according to the Indonesia Classification Regulation using the finite element approach. The longitudinal stress distribution of the vessel has been analyzed for the still water and wave condition. The maximum stress has been identified. The structural responses of the catamaran livestock carrier indicate that the proposed structure design is reliable to support the livestock transportation activities in the Indonesian waterways.**

***Keywords*— Catamaran, Livestock Carrier, FE analysis, Structural Response**

1. INTRODUCTION

Since Indonesia is an archipelago country, livestock transportation between inter-islands will expend a long sailing time. Therefore the livestock transportation services should be intended to provide the livestock well-being in such a stage as they arrive at the destination. Most of the ships which are plying international trade routes should comply with the international convention and regulation to ensure the safety of the passengers and crew also to protect the environment. In the case of livestock carrier, the live animals which are carried on the vessel are absolutely dependent on the on-board systems, because they do not have the ability to abandon the ship while an accident occurred. Meanwhile, in

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Indonesia, many livestock vehicles such as trucks, trains, and ships are not particularly designed to support livestock transportation that considered animal welfare, see Fig. 1. According to the condition, the design of a catamaran livestock carrier has been proposed to improve the transportation service, [1].

Fig. 1. Livestock Transportation using Truck and General Cargo Ship

In the previous study, [1], the hull form design of the catamaran livestock carrier was proposed. The catamaran hull form has offered a better resistance performance, especially in the high service speed. The catamaran also enlarges the deck area and improves the intact stability performance compare with the monohull. In the head sea condition, the catamaran has operability on the significant wave height above 3 meters. However, the reduction of vertical acceleration is similar to the monohull hull form, in the following and stern quartering sea condition. As continuations of the previously presented work of the development of the catamaran livestock carrier, this study is focused on the investigation of the structural response of the catamaran livestock carrier. The objective of the structure analysis was to assess the strength of the catamaran structure in fulfillment of the requirements for direct strength analysis of the Indonesia classification bureau (BKI), which includes longitudinal strength analysis and transverse strength for the still water and wave load condition.

In this study, the literature which is reviewed generally deals with the recent application of the finite element method on the strength analysis of ship structure. Andric, J. et al., [2], study the structural analysis of livestock carrier. The ship structure is designed with a large opening in the side of the superstructure. The main problems which are evaluated are the longitudinal strength and transverse strength, which is the capability of the structure has been assessed. The critical location of the high-stress concentration was identified. The rational redesign procedure has achieved structural weight gain. Rorup, J. et al., [3], study on the finite element based strength analysis of ship structure for classification approval. The generic procedures for different types of finite element analysis were presented. The guideline of the regulation, which is defined for appropriate modeling techniques such as load condition, boundary condition, and the mesh size, also the use of acceptance criteria of regulation, was explained. On the other study, Rorup, J. et al. [4], study on the load generation for strength analysis of large containers. The study introduces the software package GL ShipLoad became the standard method to generate the rule-based loads on the global strength analysis. Iqbal, J. and Shifan, Z., [5], presents an overview of the finite element modeling and analysis technique of ship structures for complex boundary conditions which are difficult for analyzing the existing classification society regulation. The historical background, the advantages and disadvantages of finite element analysis were reported along with examples related to the hull structure and structural strength. The application of the finite element method also can be found for the buckling strength

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analysis, [6], [7], vibration analysis and damage detection, [8], hull girder, ultimate strength and ship structural integrity, [9]-[11].

2. SHIP DESCRIPTION AND FRAME STRUCTURE DIMENSION

The catamaran livestock carrier has been designed with the loading capacity to transport 500 cattle and the sailing time of 7 days with the following principal dimensions:

Length overall	95.76	m
Length waterline	91.52	m
Length between perpendicular	88.00	m
Breadth	26.75	m
Height	6.48	m
Draught	2.82	m
Demi hull Breadth	5.50	m
Deadweight Tonnage	1600	Ton
Service Speed	20	Knot
Block Coefficient	0.55	

The catamaran has five decks where the pen is located on the main deck, deck “A” and deck “B”. The pen arrangement is following the regulation of the Australian Maritime Safety Authority (AMSA) Marine Order 43, [12]. The length of the pen is determined as 4 m, and the width of the pen is 3.7 m. The illustration of the pen and the general arrangement of the catamaran livestock carrier can be seen in Fig. 2 and Fig. 3, respectively.

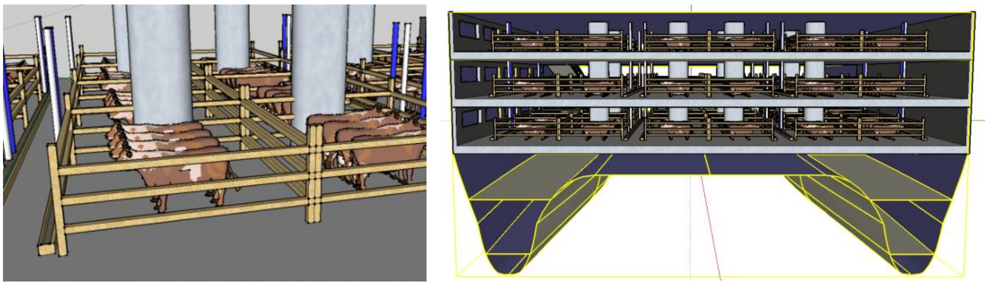

Fig.2. Design of Cattle Pens of the Catamaran Livestock Carrier

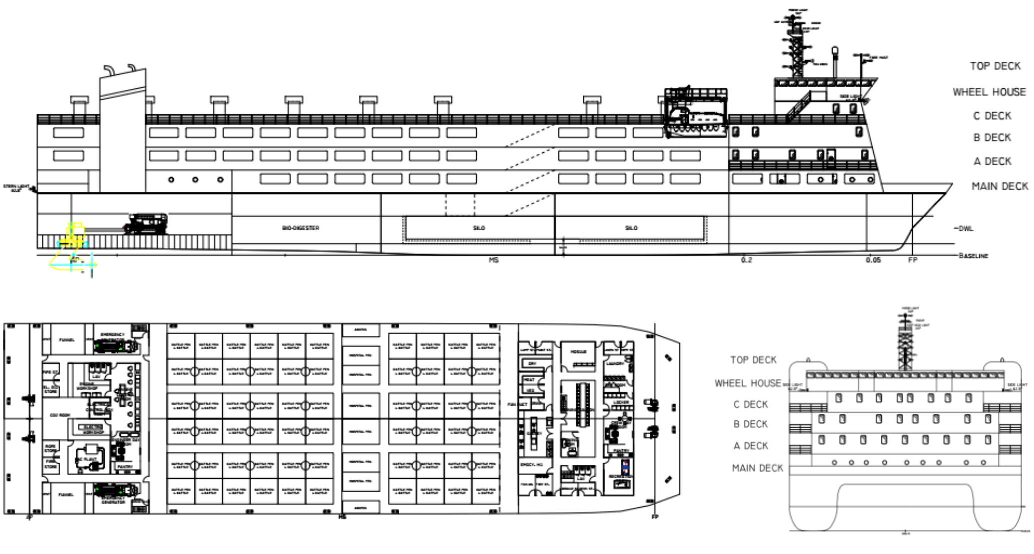

Fig.3. General Arrangement of Cattle Pens of the Catamaran Livestock Carrier

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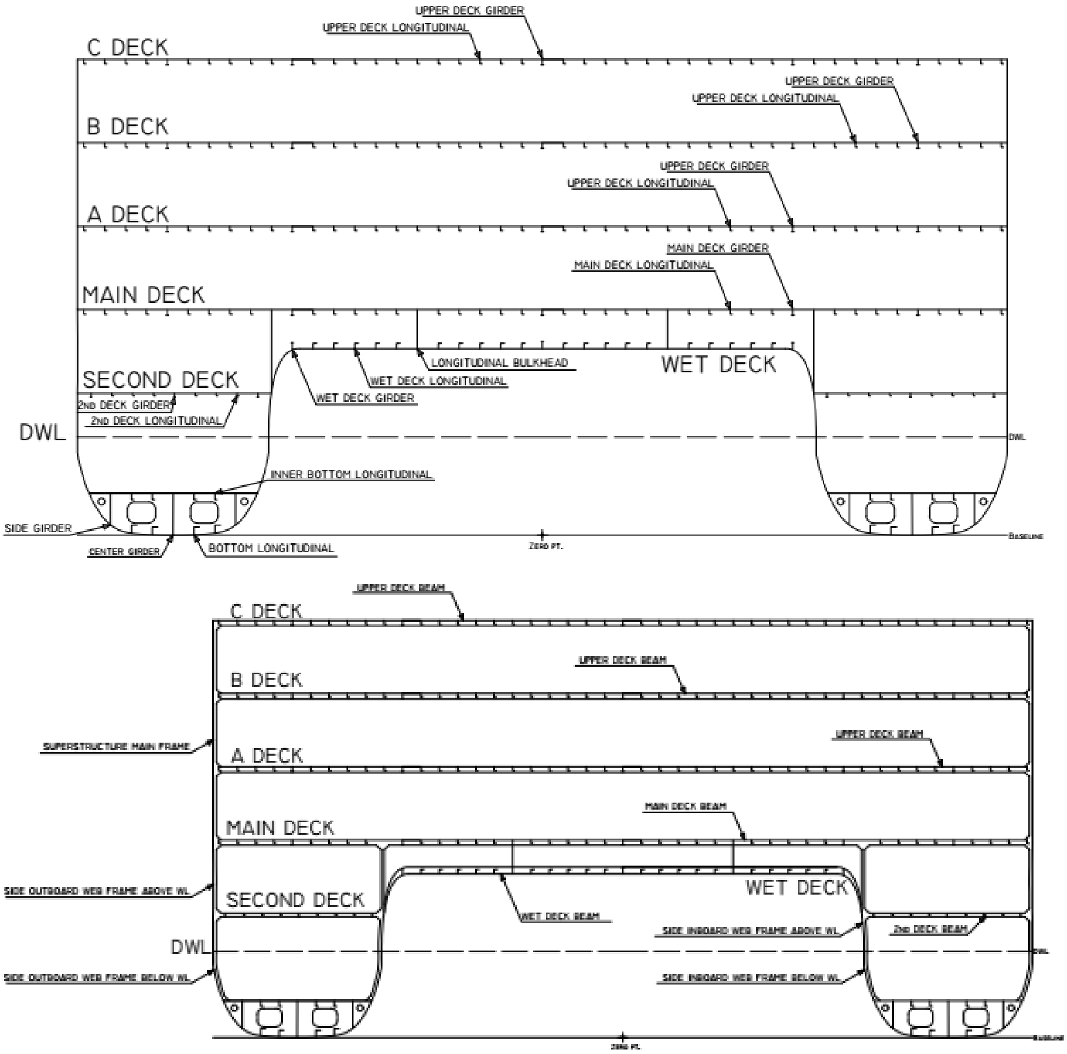

Fig.4. Midship section of the catamaran livestock carrier

Table 1: Dimension and thickness of the structure members in mm

Profile	Dimension	Plate	Thickness
Bottom longitudinal	220×160×14	Bottom plate	8
Inner bottom longitudinal	180×75×11	Inner bottom plate	9
Deck longitudinal	75×55×7	Side outboard below the waterline	9
Center second deck girder	130×8 FP 85×8	Side outboard above the waterline	12
Side second deck girder	120×8 FP 80×8	Side inboard below the waterline	9
Wet deck girder	150×11 FP 85×11	Side inboard above the waterline	9
Wet deck longitudinal	140×105×10	Second deck	4
Cross deck girder	150×11 FP 85×11	Wet deck	4
Cross deck longitudinal	220×65×6	Cross deck	4
Second deck beam	100×7 FP 60×7	Center girder	9
Wet deck beam	200×12 FP 85×11	Side girder	6
Cross deck beam	150×11 FP 85×11	Longitudinal bulkhead	6
Profile		**Dimension**	
Side outboard web frame below the waterline		320×22 FP 135×22	
Side outboard web frame above the waterline		240×18 FP 140×18	
Side outboard web frame below the waterline		320×22 FP 135×22	
Side outboard web frame above the waterline		250×20 FP 135×20	
Superstructure side web frame		120×8 FP 85×8	

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The construction of the catamaran livestock carrier is determined using a longitudinal framing system. The sidewall of the superstructure has a large opening as the type of the ship is an open livestock carrier. The ventilation system is equipped with the cylindrical ducting pipe, which is integrated as a part of the ship structure. The dimensions of the structural members of the catamaran comply with the regulation of Indonesia Classification Society (BKI). The dimensions of the frame, profiles, stiffeners, and the midship section design can be seen in Fig. 4 and Table 1.

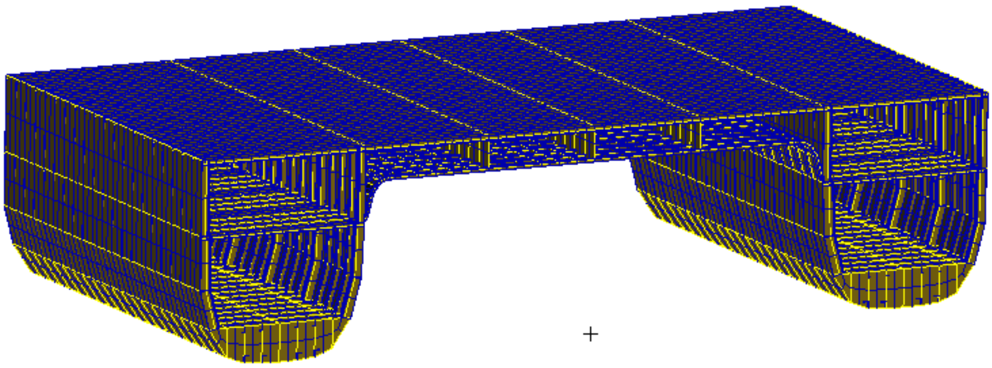

Fig.5. FE model of the parallel middle body part of the catamaran livestock carrier

3. FINITE ELEMENT (FE) MODELING

3.1. DESCRIPTION OF FE-MODEL AND MATERIAL PROPERTIES

In the view of the parallel middle body part of the catamaran, the FE model was accomplished to give deformation shape, stress distribution, and acceptability results and simultaneously provide load and boundary conditions for further structural analysis of wave condition (hogging and sagging). The FE model mesh of the catamaran livestock carrier was developed, see Fig.5, with the details are as follows:

(a) Shell constructions such as the main deck, outer side shell, inner side shell, bottom, and bulkheads were represented by the quadrilateral 4-node shell elements combined with the stiffeners, which are modeled with 2-node beam elements to increase the plate stiffness as stiffened panel construction.

(b) Triangular with 3-node elements were also applied with the defined thickness, especially for the curved geometry such as the solid floor.

(c) Side transverses or girders were modeled with 2-node beam-element (where beam theory is applicable).

(d) The solid floors were modeled with 4-node quadrilateral shell or 3-node triangular shell.

The parallel middle body part of the catamaran is contained of 11913 nodes and 24318 elements (shell elements and beam elements). Although the superstructure is supposed to have a contribution to the longitudinal strength, however, the catamaran livestock carrier model was made with the main deck area only. This assumption was made; because the modeling requirement of the classification rules usually only includes the strength deck (main deck) structures. The thickness and properties of the element were defined from the scantling calculation during the design stage. Since the net scantling approach was adopted, therefore the corrosion allowance thickness was disregarded. The lightening holes, maintenance holes, and the others, especially on the solid floors, were not modeled.

3.2. DESCRIPTION OF LOAD AND BOUNDARY CONDITION

The characteristics of the catamaran are the slender twin hull with the low block coefficient, and the weight distribution usually generates the hogging bending moment in the still water condition. It can be explained that the buoyancy at the midship is more extensive than at the ends, while the weight distribution at the ends is large due to the main engine weight and the other equipment weight at the fore-end. Because of the conditions, the maximum longitudinal stress can be occurred through the combination of maximum still water bending moment and the maximum hogging bending moment. In determining the magnitude of the bending moments, the calculation of weight distribution load and the buoyancy load was made. The illustration of weight distribution, buoyancy load, shear force distribution, and bending moment can be seen in Fig. 6 – Fig. 8.

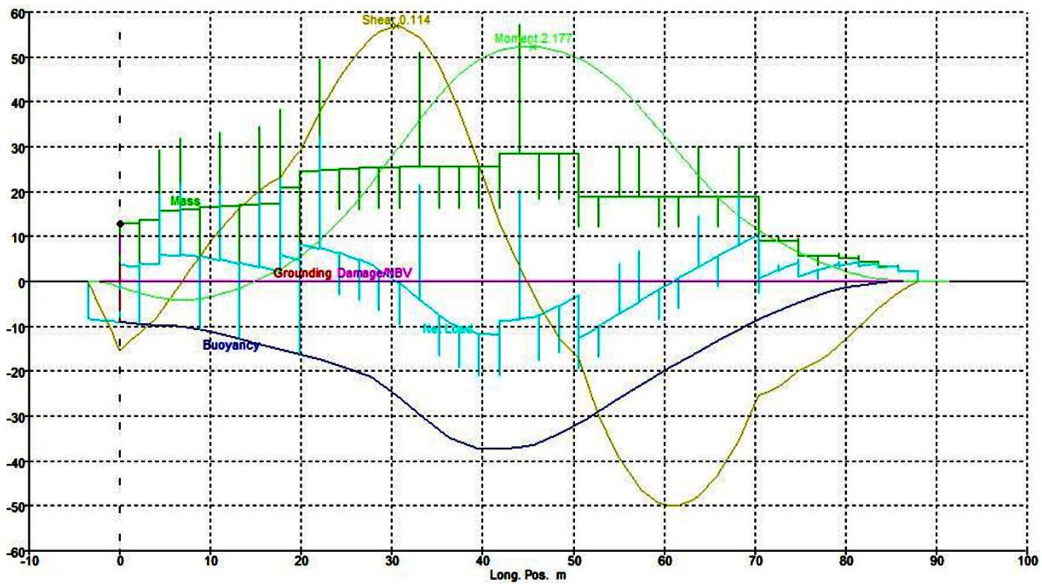

Fig. 6. Longitudinal load distribution in still water condition

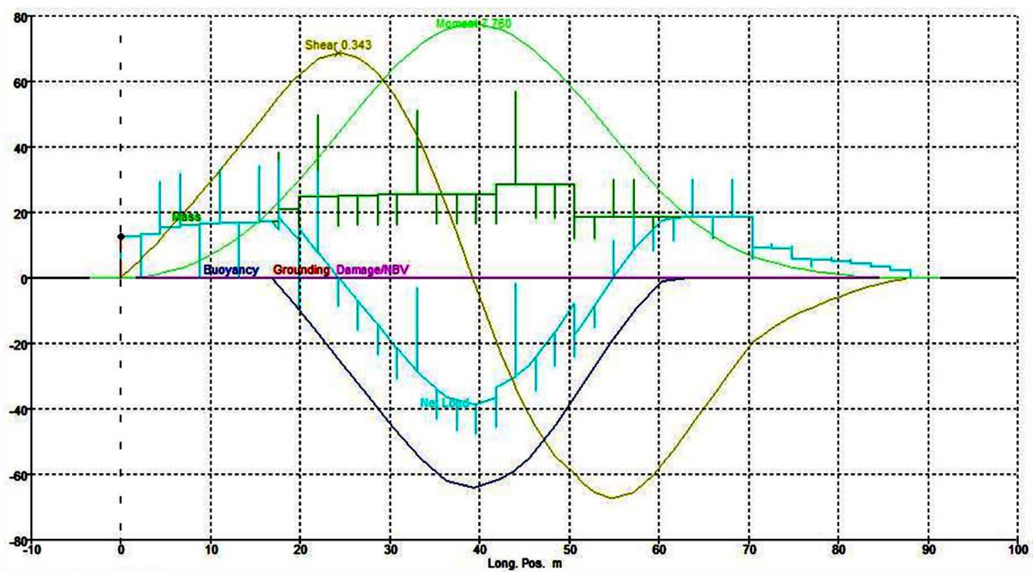

Fig. 7. Longitudinal load distribution in hogging condition

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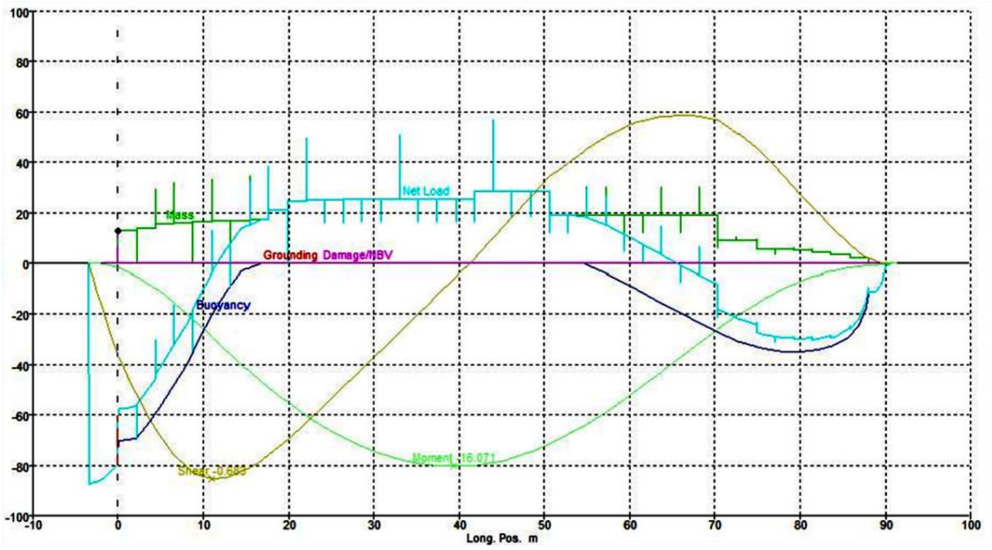

Fig. 8. Longitudinal load distribution in sagging condition

The static load distribution was defined from the distribution of lightweight and deadweight of the vessel, and the software package automatically generated the buoyancy load distribution. The additional mass, such as the main engine, deck machinery equipment and the others, are included in the calculation of the weight distribution of lightweight. The weight of the cattle, the food, freshwater and the others were included in the deadweight calculation. According to the calculation of the full load condition, the lightweight of the vessel is 772.97 tons, and the deadweight is 837.88 tons. Therefore the total displacement of the vessel is 1610.85 tons. The sinusoidal wave-induced load is defined with the wavelength as same as the ship length and the wave height of 5% the ship's length. The hydrostatic pressure of the wave load model is defined with an exerted pressure in the immersion depth of each station. The illustration of the hydrostatic pressure distribution of the wave load can be seen in Fig. 9 and Fig. 10.

According to the described load condition, the load model of the finite element analysis involves the four type of load which includes: weight (lightweight and deadweight) load, buoyancy load (still water, hogging and sagging), inertial load and the bending moment load of the each of end side of the FE model. The magnitude of the bending moments was determined from the bending moment diagram on Fig. 6 – Fig. 8

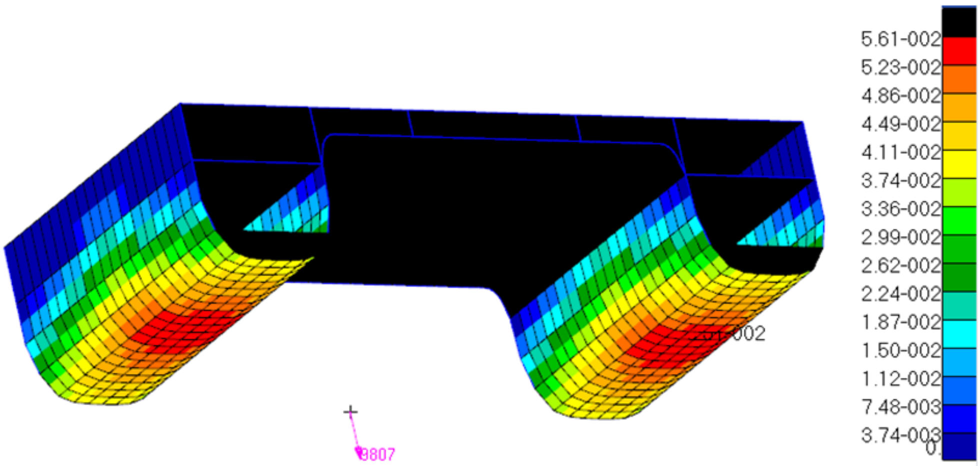

Fig. 8. Buoyancy pressure distribution in hogging condition

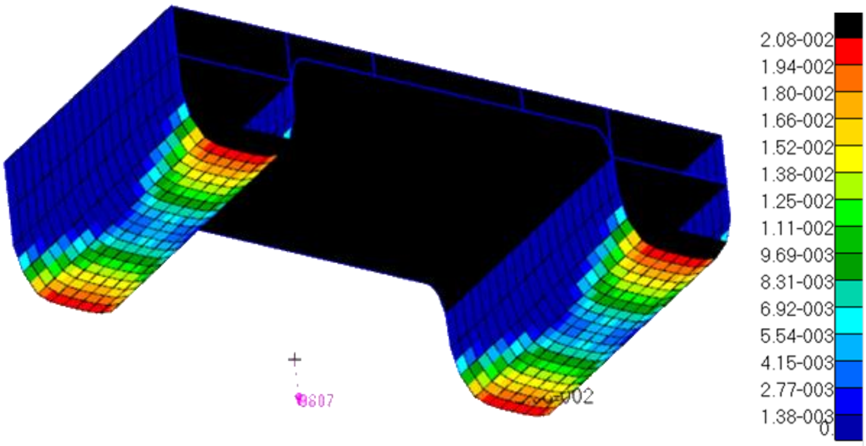

Fig. 9. Buoyancy pressure distribution in sagging condition

The next procedure of the finite element modeling is defining the boundary condition. Boundary conditions are a constraint which is needed to find the solution of a boundary value problem. The differential equation system of a boundary value problem in a domain can be solved when its boundary condition is identified. In the finite element structure analysis, boundary conditions eliminate the singularity of the stiffness matrix during the numerical computation process to find the solutions. Therefore the boundary condition should be defined appropriately to accomplish an accurate simulation result.

The boundary conditions of the catamaran model are determined by considering the classification rules for the direct strength assessment standard, [13]. Both ends of the catamaran model are defined as simply supported, which can be seen in Table 2 and Table 3. The longitudinal members of both ends are connected with the rigid link to the independent node, which is located at the neutral axis on the vessel centerline. The constraint conditions of the independent nodes are to be defined, as shown in Table 3. The illustration of the boundary conditions of the catamaran model can be seen in Fig. 10.

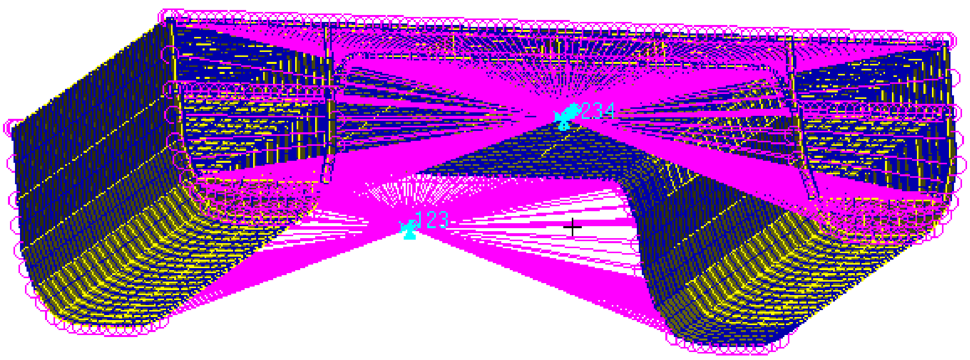

Fig. 10. Boundary conditions of the FE-model

Table 2: Rigid-link of both ends, [13]

Nodes on longitudinal members at both ends of the model	Translational			Rotational		
	Dx	Dy	Dz	Rx	Ry	Rz
All Longitudinal members	RL	RL	RL	-	-	-
RL means rigidly linked to the relevant degrees of freedom of the independent point						

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Table 3: Support condition of the independent point, [13]

Nodes on longitudinal members at both ends of the model	Translational			Rotational		
	Dx	Dy	Dz	Rx	Ry	Rz
Independent point on aft end of model	-	Fix	Fix	-	-	-
Independent point on fore-end of model	Fix	Fix	Fix	Fix	-	-

4. RESULTS AND DISCUSSION

4.1. STRUCTURAL RESPONSE IN STILL WATER CONDITION

The parallel middle body FE model provided results for the global deformation and stress distribution on the still water condition. The model was sufficient to present the response of the vessel structure. The defined load case represents the approximation of the operational condition (still water) following the cargo volume condition and the environment of the sailing route. The behavior of the structure shows an appropriate response with the hypothesis prediction that affirmed the global hogging deformation.

The result obtained shows that maximum effective stress of 41.7 MPa can be found on the inner deck of the catamaran hull. It can be explained that the fodder is located on the inner deck. Therefore the pressure which is generated by the fodder would cause the largest effective stress than the other part. The deformation of the inner deck part at the adjacent region of the maximum stress area is 5.39 mm. Instead of the inner deck, the maximum deformation can be found in the bilge area. The magnitude of the maximum deformation at the bilge area is 5.5 mm. The illustration of effective stress distribution and the deformation contour can be seen in Fig. 11 and Fig. 12, respectively.

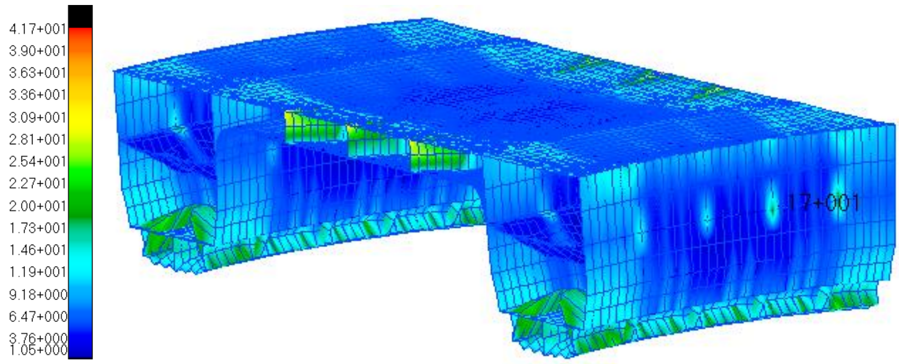

Fig. 11 The effective stress distribution (von-mises) in the still water condition

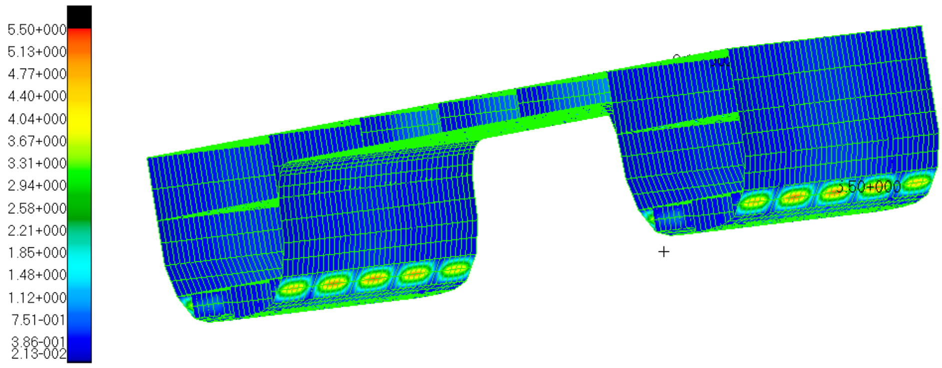

Fig. 12 The structure deformation contour in the still water condition

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4.2. STRUCTURAL RESPONSE IN WAVE CONDITION

The structural strength analysis in the wave condition has been performed using two-wave conditions, which include hogging and sagging. The parallel middle body model was adopted to analyze the structural part response and several critical areas that the maximum stress and the maximum deformation have occurred. The maximum hydrostatic pressure is 5.61×10^{-2} MPa that is defined on the maximum immerse depth of 5.1 m. The maximum immerse depth is located on the midship for hogging and on both ends for the sagging condition.

In the case of the hogging condition, the simulation results show that maximum effective stress of 114 MPa can be found on the inner bilge strake of the catamaran hull. However, the bilge strake is not in the position where the maximum hydrostatic is applied. It can be explained that the combined bending moment and the hydrostatic pressure on the fore-end might generate an enormous load of the bilge strake area. Otherwise, the effect of the boundary condition also caused the stress concentration in the adjacent area of the boundary region. The maximum deformation of the inner bilge strake is 13.8 mm. The illustration of effective stress distribution and the deformation contour can be seen in Fig. 13 and Fig. 14, respectively.

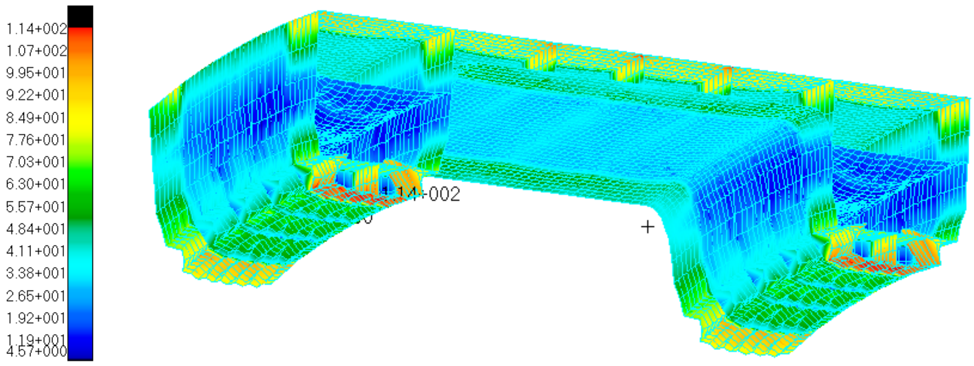

Fig. 13 The effective stress distribution (von-mises) in the still water condition

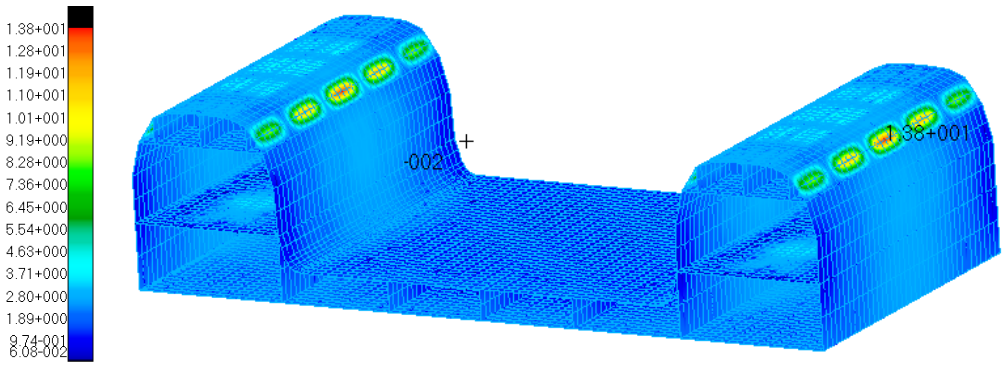

Fig. 14 The structure deformation contour in the still water condition

In the case of the sagging condition, the simulation result obtained shows that the maximum effective stress of 63.4 MPa can be found on the cross deck of the catamaran hull. The global response deformation of the catamaran model has shown a different curvature form (sagging form). It can be explained that the sagging wave generates a negative bending moment. Furthermore, it is indicated that the simulation result has a good agreement with the bending moment calculation that is presented in Fig. 8. The maximum

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stress also represents the effect of the boundary condition that causes increased stress in the adjacent area of the boundary region. The maximum deformation of 8.08 mm can be found on the inner deck part. The illustration of effective stress distribution and the deformation contour can be seen in Fig. 15 and Fig. 16, respectively.

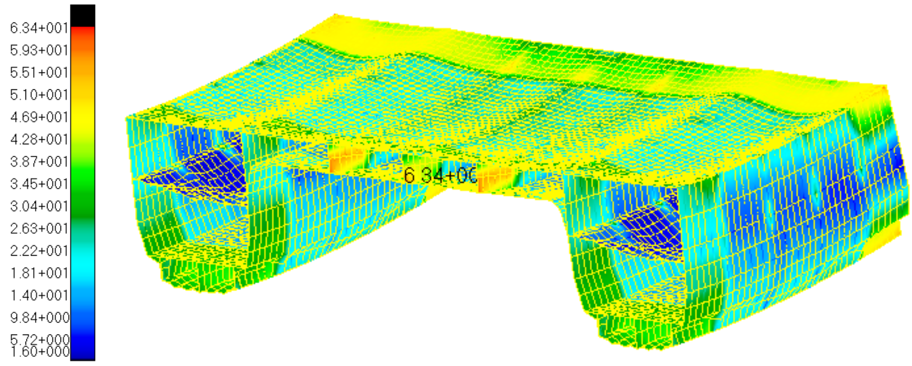

Fig. 15 The effective stress distribution (von-mises) in the still water condition

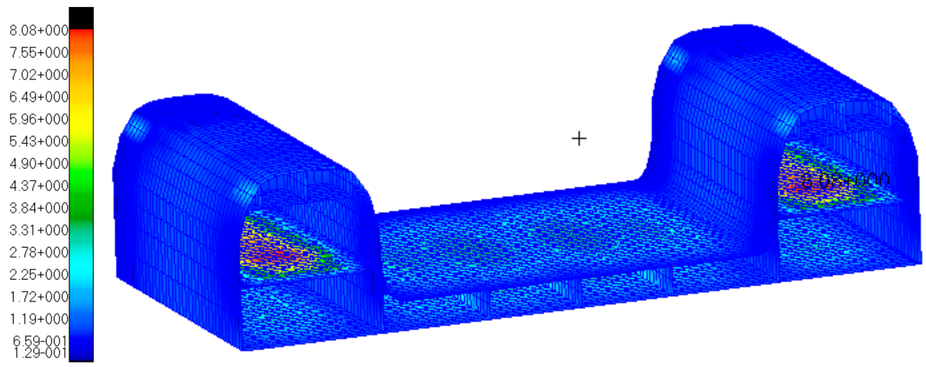

Fig. 16 The structure deformation contour in the still water condition

5. CONCLUSIONS

Presented work represents the investigation of the structural response of the proposed catamaran livestock carrier was successfully made. This study also represents progress in developing the catamaran livestock carrier as an alternative of vehicle, especially in the assessment of the catamaran hull structure reliability to support the operational activities.

The evaluation of the parallel middle body part strength was successfully calculated using the finite element method. The finite element model is capable of simulating the catamaran structural response. The maximum effective stress of 114 MPa has occurred in the hogging condition. It is significantly smaller than the allowable stress of the classification rule requirement (175 MPa). The maximum deformation of 13.8 mm was occurred on the bilge strake area in the hogging and still water condition. In the sagging condition, the maximum deformation of 8.08 mm has occurred on the inner deck area. It is indicated that the structure of the catamaran livestock carrier is reliable to support the operational load and comply with the classification requirement.

The future implication of the research result has shown that the proposed design structure able to be applied to support the operational load of the catamaran livestock carrier. However, the result of the analysis was limited to moderate and normal sea state

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Indonesia waterways conditions. Therefore it should be examined the structure response during the severe sea environment as the future works.

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