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Hydrodynamic and Structural Investigations of Catamaran Design

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Abstract

The type of hull in the catamaran is developed by following the design criteria. A catamaran has advantages over a monohull in terms of broad layout, excellent stability, and obstacles on small vessels. The catamaran design follows the semi SWATH type design by having two hulls with a small hull front corner and modeling on INCAT wave-piercing catamaran to determine the structural response to the ship, and the wave slamming process. In the simulation analysis using fluid-structure interaction with RANS and also the strength of the catamaran structure using the FE method and large base scale. In modeling also to show the hydroelastic response to the ship structure that makes the dynamic interaction between waves and ship structure more practical. Then, the design optimization of the catamaran is directed to the addition of keel fins and the application of titanium materials.

Keywords: INCAT Catamaran; FE method; FSI (Fluid-Structure Interaction); Keel fins

1. Introduction

In recent years in the sector of shipping, the use of the hull of the ship has experienced quite rapid development, including in subject to improve hydrodynamic performance and accidental resistance (Prabowo et al., 2019; 2020a;

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b). It is starting from a monohull, which has one stomach, and until its development, there is a multihull that has more than one hull, which can have a positive impact on the maritime world. Since this development, the researchers have emphasized more than one hull (multihull). The hull to be investigated is on the catamaran. This type of catamaran ship was developed to meet the design criteria. Besides that, the catamaran has advantages over monohulls from the aspect of spacious layout, excellent stability, and obstacles on small vessels (McVicar, 2018). In the shape of the catamaran hull, there is also a symmetrical and asymmetrical hull. The symmetrical hull is, in a sense, a hull that has two hulls with the distance between the hulls. At both ends of the ship's hull has the same shape. Asymmetrical hulls have the identical two hulls but at the end of the hull have opposite or different directions.

In further developments, the catamaran design follows the semi SWATH type design (Begovic et al., 2019) by having two hulls with a small hull front angle. The advantage of the catamaran is to increase buoyancy upward at the junction between the ship's hulls by entering deeper water. In modeling, the design of the piercing catamaran wave developed to reduce the response of waves in moderation with buoyancy above the water surface. In the analysis of the INCAT wave-piercing catamaran modeling can determine the structural response to the hull and wave slamming process. According to Tezdogan et al. (2016), by modeling between hydrodynamic interactions with a full-scale ship simulation and based on simulations on the Navier Stokes (RANS) equation, it can be seen as the shock wave review. Then the ship structure that was tested with towing tanks can find out the structure of the ship in more detail about the waves (Insel and Molland, 1992).

2. FSI analysis of catamaran slamming

On the hull with the type of piercing catamaran, the wave has a slender in front of the ship on the multihull. It stretches to form like a jaw between the middle arc and multihull. At the bottom on the side of the central arc, there is an immersion since it can be filled with water. In previous research, there were still many who used experimental methods compared to numeric methods. The experimental process uses the full scale to look for characteristics of the whipping response (short vibration) of the hull (Storhaug, 2014). In its development with a hydroelastic segmented model to regulate control of waves and slamming mapping at ship speed, wave height, and frequency of waves meeting at sea. In the type of piercing catamaran, analysis is possibly conducted using one-way and two-way interaction simulations on Fluid-Structure Interaction (FSI) with unstable RANS Computational Fluid Dynamics (CFD). The most apparent difference in the piercing catamaran is the complexity of fluid flow and vast distances on the time scale. In the simulation of one-way and two-way interactions have differences in the amplitude of gastric motion. In two-way interactions have parts of the body that are rigid in movement while the one-way interaction has a rigid body separation with bending motion on the ship. In his approach with one-way and two-way interactions with the structural domain and calculated after the fluid domain. Then the one-way interaction is similar to the approach:

$$M^R\ddot{x}^R = F^R_{FK} + F^R_D - A^R\ddot{x}^R - B^R\dot{x}^R - C^Rx^R \quad (1)$$

where, M = mass matrix; x = motion vector of the hull; F_{FK} = Froude-krylov style; F_D = diffraction force; A = additional mass matrix; B = damping matrix; C = stiffness matrix; R = movement of rigid objects.

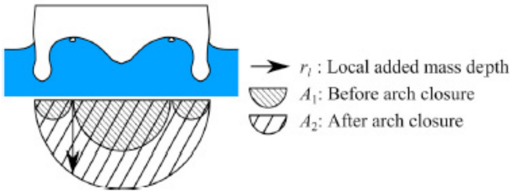

Fig. 1. Before and after adding sectional mass (Insel and Molland, 1992).

In a two-way interaction with the gastric pressure distribution solution and can not be separated. Simulations performed on two-way interactions using RANS fluid solvers are unstable and have never been done before. Therefore, to find the whipping response characteristics, there is a comparison between one-way interactions with two-way interactions. According to this research, the approach taken in one-way interaction was obtained with a new hemispherical additional mass model and the time variation in the increased other mass in the piercing catamaran (see Fig. 1). After that, the advantages of one-way interaction can eliminate the need to form a fluid domain and transfer the response to each structural. That way, the gastric piercing catamaran on structural parameters has a slam force with little effect but changes in the gastric flexure (Insel and Molland, 1992).

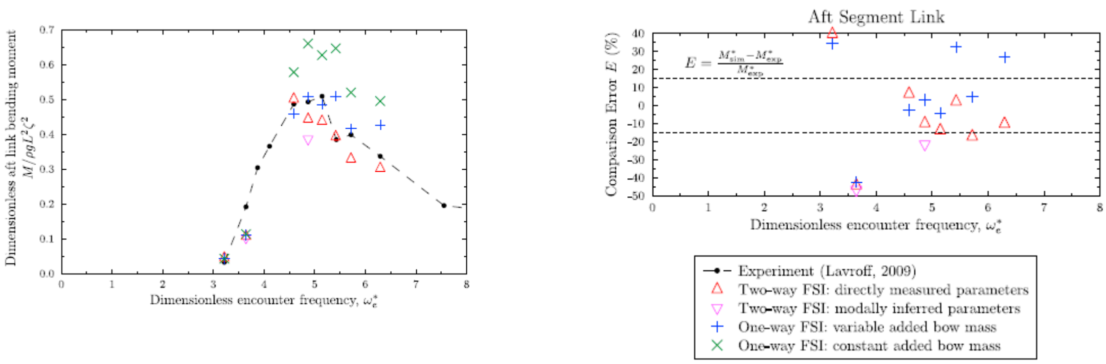

Fig. 2. Simulation of the bending moment dimensionless and experimental at the stern segment (Insel and Molland, 1992).

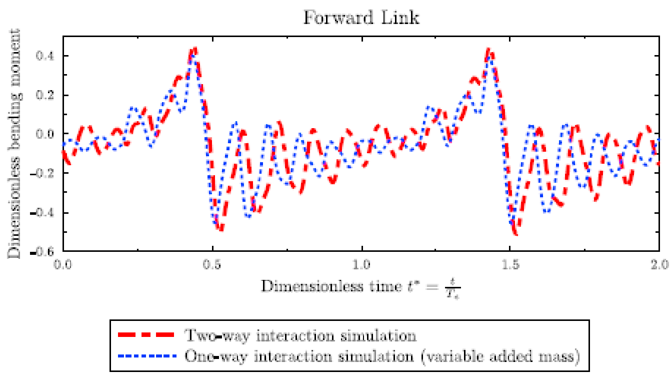

Fig. 3. Simulation of transient bending moments in two-way and one-way interactions with additional mass (Insel and Molland, 1992).

On the verification results of the model-scale experiments, the convergence study related to the iteration number, grid distance, and size on numerical simulations was calculated respectively from the lift force of 5.4%, the pitch of 2.6%, and the central arc of 11.3%. In Fig. 2, the validation on the heave and pitch on UV validation is 7.4% and 5.6%. The use of further validation with gastric VBM functions as a variable to support the central arc force. VBM obtained at UV validation was 15.1%. The combination of one-way interactions with two-way interactions can be said to be consistent. Fig. 3 explains the results of the magnitude of hull girder vibrations in a one-way interaction simulation with variations in time mass, similar to two-way interactions.

3. Ultimate strength of catamaran structure

On catamarans, which have two hulls, can be designed with a limited design in shallow water, and the hull structure also has a vertical bending moment at the sideload. In previous studies, Xu et al. (2019), explained that the experimental method on the structure of the catamaran hogging bending moment occurred with a ratio of 1/20 scale on the ship. In this method, a single hull structure was tested for the use of a double hull structure. The result is that this method has not been able to simulate the overall collapse mode in a double hull. Then, the results from previous specimen experiments obtained validation and calibration from Finite Element simulation (FE), which can be developed on a real scale ship structure. The main objective of this research is to analyze the longitudinal strength due to double hulls that resemble monohulls (Fig. 4). By using the FE method and a large base, a scale can determine the strength of the longitudinal and structural strength of the ship.

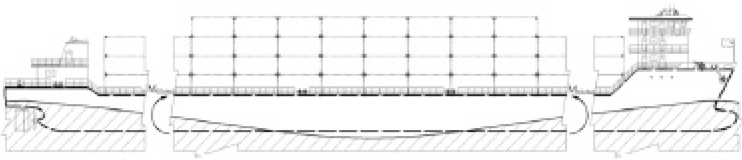

Fig. 4. A prototype of the catamaran (Xu et al., 2019).

At the research stage carried out on this catamaran structure, design modeling was carried out with a basic scale approach that contained the ship's prototype. Variables that are sought are bending moment, acting force, length, and plate thickness. After that, make a comparison between numerical simulations with experiments on prototype ships and large scale specimens (Xu et al., 2019). The results of research conducted by Xu et al. produced an appropriate analysis between numerical simulations and experiments. Obtained buckling strength on the ship's structure becomes very important for the catamaran as a whole because it experiences a bending moment that is vertically curved. The ultimate strength between ship prototypes and large-scale specimens has weaknesses in the scaling design aspects. Thus, further development is carried out by increasing the longitudinal strength of catamaran ultimates in cross-deck structures and using mild steel by increasing its melting stress. Other references, e.g., Heggelund et al. (2000) also discuss similar subjects, but the research was more dedicated to assessing transverse strength.

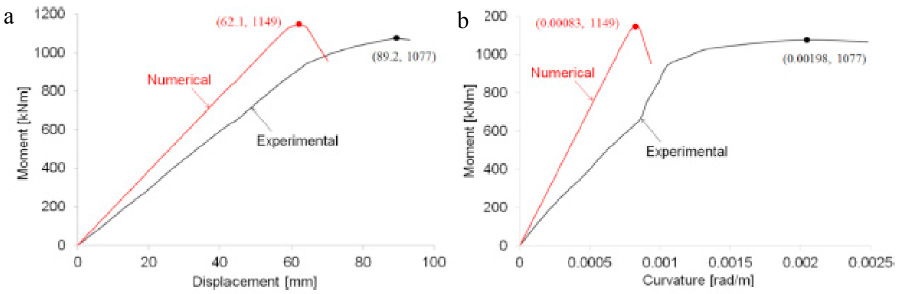

Fig. 5. Analysis FE curves: (a) moment-displacement; (b) moment-curvature (Xu et al., 2019).

The results of the research using the FE analysis method is shown in Fig. 5, explaining the existence of vertical bending moments in the moment-testing curve in experimental experiments with transfers of 89.2 mm and bending moments of 1077 kNm and on numerical methods using 62.1 mm and bending moment of 1149 kNm. In the moment-curvature curve in experimental tests with a curvature of 0.00198 rad/m and a bending moment of 1077 kNm and numerical methods with calculations of 0.00083 rad/m and a bending moment of 1149 kNm. The results of these curves have ultimate strength at maximum structural capacity and can be determined on the hull structure. Then these results have real differences in the slope produced experimentally and numerically.

4. Welding characteristic of autonomous catamaran

The welding process in the catamaran is carried out using two methods, namely Gas Tungsten Arc Welding (GTAW) and Gas Metal Arc Welding (GMAW) (shown in Fig. 6) (Chen et al., 2019; Wu et al., 2018). The main ingredient in the manufacture of ship hulls uses Aluminum 5083, which is one of the steel replacement materials with the advantage of reducing fuel consumption and increasing efficiency. Comparison of the GTAW process with

GMAW on Aluminum 5083 material occurs the GTAW process has weld strength and tenacity without any defects in the microstructure. Several factors affect the design, namely, plate thickness, welded joints, and the material used.

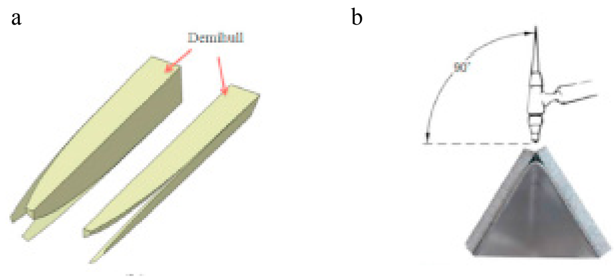

Fig. 6. Catamaran hull geometry: (a) Catamaran design, and (b) Welding conditions on the hull (Honaryar et al., 2020).

In previous research, according to Honaryar et al. (2020), in the analysis method used in the welding characteristics of the catamaran, there was a computational method development that is finite element analysis (FEA), which affects different parameters with deformation due to the welding process. Honaryar et al. (2020) also explained that on thin plates, the structure uses the FEA method with thermal-elastic-plastic. The results in the method process of distortion buckling occur, which is a severe problem in welding of thin-walled structures. In this research, the used technique is numerical methods or TEP FE analysis with sample experiments on 5083 aluminum sheets. The results of TEP FE are obtained by comparing results of validation and experiment in terms of the deformation that occurs due to the angle parameters and the length of the outer angles of the joints. Also, on the FE elastic analysis with ZRASV welding joints on the strain or deformation theory based on welding speed. The deformation result shows an efficient and effective way of the aluminum welding structure accurately.

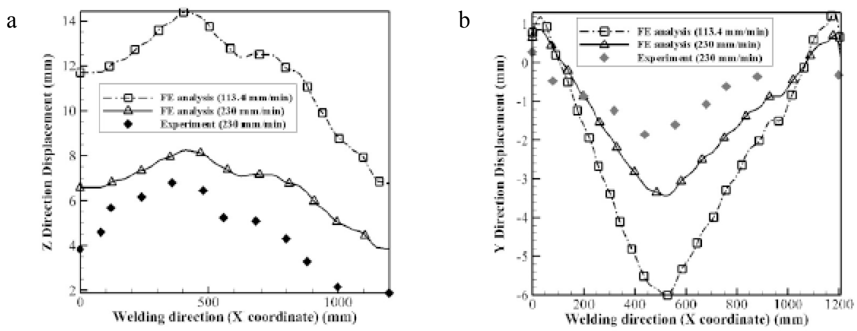

Fig. 7. Comparison of welding-displacement in the FE and Experimental methods: (a) line 1; (b) line 2 (Honaryar et al., 2020).

The results of the validation, as presented in Fig. 7 with the FE analysis method and the experimental method are obtained on the curve between line 1 and line 2 using distortion, which causes welding. The curve presented the FE method at a low rate of 113.4 (mm⁄min), a high rate of 230 (mm⁄min), and the ZRASV experimental model with a welding speed of 230 (mm⁄min). These results proved that both methods are well-proven.

5. Wave load effect

In conventional catamaran hull designs, it is very effective for small wave areas because it has two or double hulls on a flat wet deck section. But the hull is not very effective when there is an impulsive slam load on the bow, which causes structural damage to the hull. The semi-SWATH type has a type of hull that can occur a smaller increase from the buoyancy force to the front of the vertical hull. Then the INCAT wave-piercing catamaran hull design was found that could reduce the wave response in moderation and increase buoyancy in the front hull. In previous research, according to Davis et al., conducted trials on full-scale ships and model testing. In its development, there is a method with a simulation application with the Navier-Stokes (RANS) equation (Sheng, 2020). At the INCAT catamaran, sea trials with TSK wave radar were carried out by measuring the wave height and strain to measure unstable pressure on the ship's structure. In this research, modeling was made with a 112 m INCAT catamaran design to measure the load waves during slamming and movement response. The parameters used in the model and full scale are:

$$w_e = (2\pi f_e)\sqrt{L/g} \tag{2}$$

where, L = ship length (m), g = acceleration of gravity (m/s^2), f_e = wave frequency (Hz).

By using model experiments, it is obtained that the controlled wave test under conditions that are not suitable at full scale. The purpose of the experiment is to show the hydroelastic response to the ship structure that makes the dynamic interaction between waves and ship structure more practical.

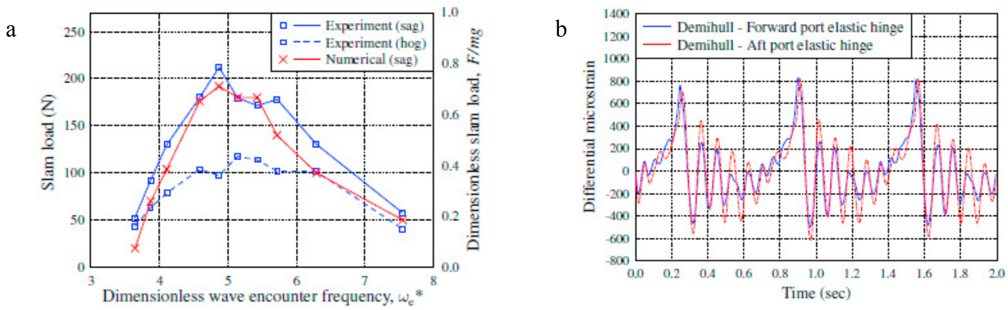

Fig. 8. (a) The slam style of the INCAT catamaran; and (b) Simulations using RANS of demihull (Lavroff et al., 2017).

In experiments using towing tests can be used to investigate slamming responses in the design of the piercing-wave catamaran. The results of the experiments conducted by RANS simulations on the scale of the model obtained slam peak load occurs at the frequency of encounters with the scale of the experimental model. Then, the hydroelastic modeling is very influential on the slamming load with an overall value similar to the duration of the slamming load and the period of the structural whipping vibration. The results of the research can be seen in Fig. 8 (a) showing an experimental model at a maximum slam strength of 212 N and a numerical method of a slam strength of 192 N at a 90 mm wave with a high speed of 2.89 m/s. The curve also explains variations in peak slam force and frequency in ordinary waves. In Fig. 8 (b) shows the data of the arc middle strain and elastic hinge half hull at-sea trials (Lavroff et al., 2017).

6. Fundamental concept in catamaran design

On the basic concept of ship design, specifically sailboats, four models are designed, namely sloop, Ketch, catamaran, and trimaran. The model that is designed leads to the main design, which is the design between sailboat and catamaran. The design is commonly called Hull-Mono-maran (MHM-maran). The hull design is similar to a catamaran. Based on the criteria of the ship, there are two categories, namely, racing ships and cruises (Song et al., 2010; Könnölä et al., 2020). In terms of ship hull, the catamaran has the advantages of being lightweight and fast. After that, in terms of agility, the catamaran has a pretty good maneuverability. Also, in terms of stability, it has an excellent level of stability because of the existence of two hulls that can defend the ship over the waves (Karlson, 1993). The catamaran has the addition of a keel below the ship's hull. The keel is the most important additional feature that functions on the stability of the vessel.

The type of keel can be divided into three types, namely winged, torpedoed, and fin. Keel, which is generally used, is in the keel fins because this type has a long fin down and friction directly with water. Lack of keel fins when the hull hits the lowlands with little water. In addition to the rocky area that can damage the keel to crack and break. The use of suitable materials in the hull is likely in fiberglass, aluminum, titanium, and stainless steel. The material can be used because it is primarily resistant to rust. The nature of the material has a difference, e.g., titanium possesses light and durable properties, while in terms of expensive costs, and in terms of processes that are difficult to do. In aluminum in terms of light and strong but heavy, while in terms of price cheaper than titanium. So in use for the structure of the hull can use two materials as needed.

7. Optimization of catamaran structures

In choosing the optimal hull design is very important for the main parameters of the designers. Hull design using numerical methods and computer assistance applications that make it easier to calculate to optimize the structure of the ship (Derollepot and Vinot, 2019). That way, ship optimization can find the optimal position of the ship's structural elements. The purpose of this research is to reduce structural weights. In previous research, there was a genetic algorithm (GA) as an efficient tool for structural optimization. GA serves to improve the structure of the ship. In the modeling of the hull structure using the Austal Auto Express 82 design model that has been developed by Austal. The structural material of the design of this ship uses aluminum. There are two uses in aluminum, namely 5083-H111 aluminum alloy for plate elements and 6082-T6 aluminum alloy for extrusion bulbs. There are parameter controls that can function to search according to the designers and speed up the process of modeling and analysis of ship structures (Sekulski, 2009).

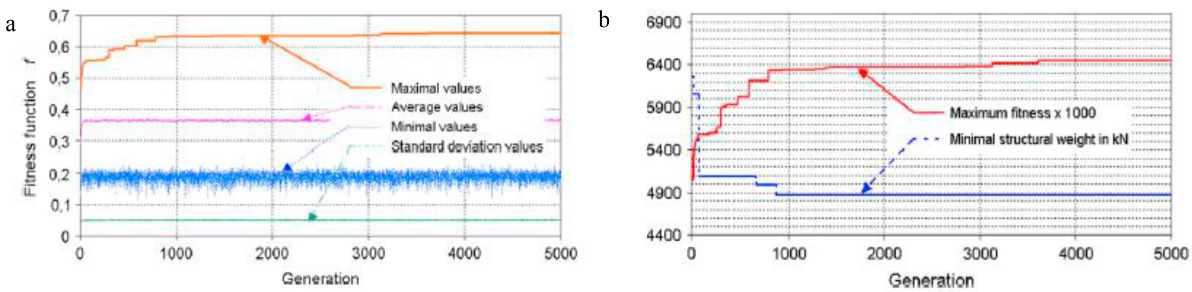

Fig. 9. The concept of genetic algorithm (GA): (a) the fitness of dimensionless function values; and (b) the value of maximum fitness and minimal structural weight (Sekulski, 2009).

In Fig. 9 (a) shows a graph of the maximum, average, minimum, and variation values in 5000 generations. On the chart, there is an average value of 0.645 and a nearly constant standard deviation of 0.075. In Fig. 9 (b), the comparative value of the fitness function, and the minimum value of the structure weight is more than 5000 generations. In this research, the concept of genetic algorithm (GA) can be used practically and appropriately. This concept can reduce the structural weight of the ship by including other criteria such as production costs. Besides, the obstacles that occur in strength, fabrication, and standardization are not so difficult. The use of genetic algorithms (GA) can be developed by optimizing the topology and size of the hull structure. In its development between topology and size of the hull structure that can increase the number of generations and the number of individuals to ensure satisfactory convergence of the optimization process. That way, the concept of the Genetic Algorithm (GA) is a tool that can evaluate and check the performance of variants on an obstacle, e.g., the value of an objective function and the value of a fitness function.

8. Conclusions

In the research conducted, it can be concluded that in the hull of the piercing catamaran, there are several methods used from starting the simulation of one-way interaction and two-way interaction with FSI (Fluid-Structure Interaction). In this trial, structural parameters have a slam force with little effect, but there is a change in the bending of the hull. On the strength of the catamaran structure, using the FE method and a large base scale can determine the longitudinal strength and structural strength of the ship. In the selection of welding methods on the hull structure, the

GTAW process with GMAW on the Aluminum 5083 material occurs, the GTAW process has the strength and tenacity of the weld without any defects in the microstructure. Then on the effect of waves on the hull cargo carried out trials at sea with TSK wave radar by measuring wave height and strain to measure unstable pressure on the ship's structure. Hydroelastic modeling is very influential on slam loads with general values similar to the duration of slam loads and the period of structural whipping vibrations. There is also a fundamental concept that is suitable for catamaran ships with the addition of fins to the hull with material properties that meet the needs of the water surface. The keel type fins and materials from titanium and aluminum can make the ship's structure more durable and more resistant to waves.

Acknowledgments

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