

Effect of Bulbous Bow on Ice Resistance of Ice Ship

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Paper History

Received: 28-October-2018

Received in revised form: 30-October-2018

Accepted: 30-October-2018

ABSTRACT

Ice resistance is very important in design of an ice ship due to its relation to the propulsion system. Bulbous bow ship economically has advantage during sailing in open water due to lower resistance compared with an ice bow. On the other hand, the bulbous bow ship has higher ice resistance due to bulbous bow. This paper discusses effect of bulbous bow on ice resistance of ice ship using Finite Element Method. In the simulation, the interaction of bulbous bow-ice was detected using the Coupled Eulerian-Lagrangian. Simulation was run at ship speeds of 0.4 m/s and 0.5 m/s at 0.5 m of ice thickness. It was founded that during ice crushing, the pressure changes that occur in the hull are directly combined with changes in the internal energy of the ice. The ice resistance increases due to buckling and bending created by bulbous bow.

KEY WORDS: *Bulbous Bow, Ice Resistance, Ice Ship, Finite Element Method, Coupled Eulerian-Lagrangian*

NOMENCLATURE

FEM	Finite Element Method
CEL	Coupled Eulerian-Lagrangian
DAT	Double Acting Tanker

1.0 INTRODUCTION

Resistance of ships at the ice level is a very basic and important field in the early stages in ice class ship design because it is closely related to ship propulsion and determines power of ship engine. Determining the ship resistance in the level ice is more complex than in the open water due to the changing characteristic properties of ice and icebreaking phenomena. Ice resistance is defined as the time average of all longitudinal forces due to ship-ice interactions.

The phenomenon of interaction between ice and ship has been studied by researchers through empirical mathematical simulation. The empirical mathematical can be used to determine the power needed by a ship to travel through the ice sheet on certain characteristics according to the desired speed. They can also be used to gain insight into the influence of the hull form on ice resistance. Lewis et al. (1970) proposed semi-empirical which was developed based on a number of experimental data of ice breakers which included full scale testing on lakes and sea ice and test the model in fresh ice and sea [1]. The method has a semi-empirical relationship between ice resistance and the parameters that characterize ships and ice sheets. The empirical formula consists of ice breaking, friction, ice buoyancy and momentum. Crago et al. (1971) described a set of model test in "wax-type" ice on 11 icebreakers [2]. Enkvist (1972) studied three icebreakers: Moskva-class, Finn carrier, and Jelppari [3]. Milano (1973) made a significant advance in the purely theoretical prediction of ship performance on ice based on conservation energy [4]. Vance (1975) obtained an "optimum regression equation" from five sets of model and full-scale data, of the Mackinaw same data as used by Lewis et al. (1970) [5, 6]. Lindqvist (1989) developed a formula to calculate ice resistance based on many full scale tests in the Bay of Bothnia [7]. Keinonen et al. (1996) did research on resistance of icebreaking vessels in level ice and developed a formula based on results of a study of escort operations involving five icebreaking vessels [8]. Daley, et al (1997 & 1998) proposed

a level ice resistance formula with some empirical parameters by developing Lindqvist's formula [9, 10]. Jaswar (2002 & 2005) proposed a method to predict ice resistance of a ship running in unfrozen and frozen ice channels and level ice [11, 12]. Su et al. (2010) stated that is often difficult to make the good relation between model scale test to full scale condition [13]. This is the current weakness in the design of an ice class ship. Jeong et al. (2010) proposed new ice resistance prediction formula for standard icebreaker model using component method of ice resistance and also predicted the model test results to full-scale using calculated non-dimensional coefficients [14]. Continuing the previous research, Tan et al. (2013 & 2014) studied the effect of the propeller-hull-ice interaction of a dual-direction ship during running astern obtained from model tests on applied to the numerical procedure [15, 16]. The model tests were conducted by Leiviska (2004) on a model of the M/T Uikku to investigate the propeller-hull-ice interaction [17]. The numerical procedure is in turn used as a performance prediction tool to supplement the model test data to investigate the thrust deduction in ice. Hu et al. (2015 & 2016) discussed several numerical methods based on Lindqvist, Keinonen, Riska and Jeong to calculate ice resistance and then calculated results are compared against model test results [18, 19]. The prediction of ice resistance of icebreakers has different accuracy and also the empirical methods were under estimates for double acting tanker. Jeong et al. (2017) presented a semi-empirical model to predict ship resistance in level ice based on Lindqvist's model [20]. Contact between the ship and the ice was assumed a case of symmetrical collision. Efi et al. (2014, 2016, 2017 & 2018) has studied performance double acting ship during running in level ice [21-27].

Design of an ice class ship requires considering the performance, adequate hull and strength of machinery and good functioning of the ship in ice condition and open water condition. The ice bow economically has inescapable disadvantage during sailing in open water due to higher resistance compared with a common bow. Researchers have proposed a Double-Acting Tanker which can sail astern functionally as an icebreaker in ice bound and ahead in open water. The stern part of DAT is additionally strengthened to break ice and podded propulsion systems. It is generally recognized phenomena of hull-ice-propeller is very complex and difficult to be understand, therefore model and full scale ice tests has been conducted to determine ice resistance of Double Acting Tanker. This paper discusses on effect of bulbous bow on ice resistance of a ship with conventional bow sailing in ice bounded condition which is analysed using Finite Element Method.

2.0 FUNDAMENTAL THEORY OF ICEBREAKING

2.1 Phenomena of Icebreaking

Under an assumption of elasticity phenomena, bending moment of ice is a predictable manner. If C_{1l} is depth of ice cusp and C_{2l} is length of ice cusp, the physical process of icebreaking can be observed based on plate bending theory as shown in the Figure 1. In continuous icebreaking the process of individual icebreaking does not act on the same tone. The hull may rub against ice shards where the bilge opens a channel that is wide enough and clean

enough to allow the hull to transit the ice sheet.

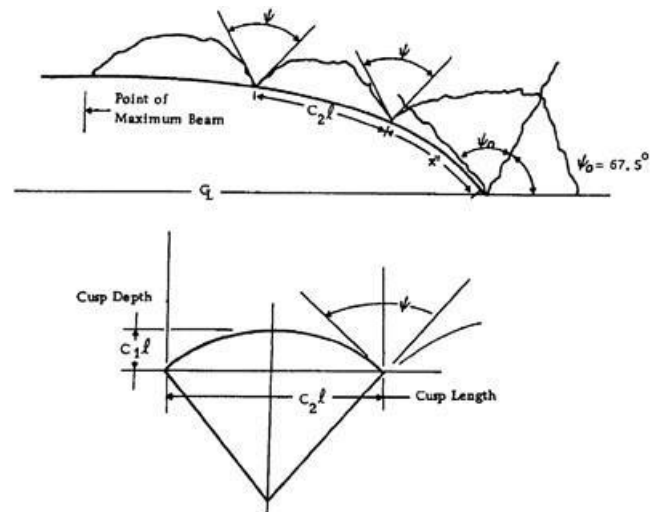
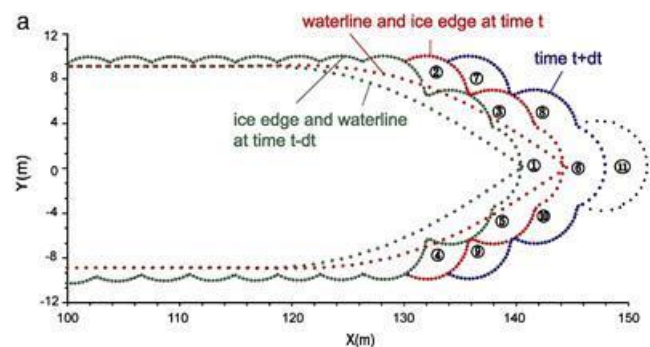


Figure 1: Idealized bending model of icebreaking (l denotes the characteristic length of ice) (Milano, 1973) [4].

Ship motion can affect cyclic processes by significantly changing contact geometry and loading patterns, which results in different levels of ice sheet loading. The important non-cyclic process also occurs due to ice failure that is not simultaneously around the hull. The characteristics of icebreaking make it realistic to investigate problems from the point of view of the time domain and examine dynamic processes with icebreaking patterns rather than individual breaking events.

The nodal model for the calculation of ice-ship interaction is illustrated in Figure 2.a. The maximum principal bending stresses to break the ice are shown at peak points 1, 8 and 11 as shown in the Figure 2.b. The maximum bending stresses are located at the centre of contact point at edge of waterline. The crushing momentum forces at waterline and ice edge at time (t) are shown at points no 2, 3, 4 and 5. Similarly, the momentum forces at waterline and ice edge at time difference ($t+dt$) are shown at points no 7, 8, 9 and 10.



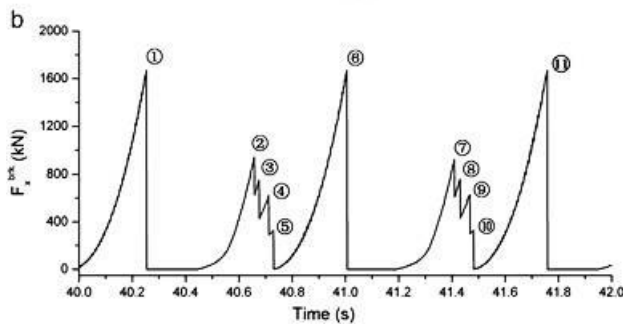


Figure 2: Ice-ship interaction and corresponding breaking force (Tan et.al 2013) [15].

2.2 Bulbous Bow

Concept of double acting ship has been developed since 1990 by Kvaerner Masa-Yards Arctic Technology Centre which known as Aker Arctic Technology Inc., a Finnish company. The idea to build ice breaking merchant ship appeared to eliminate ice breaker as assistance when merchant ship sailing in ice conditions as mentioned by Kubiak (2014) [28]. Double acting ship was designed to run ahead in open water and astern in ice conditions. Design of ice-going ships requires considering the performance, adequate hull and strength of machinery and good functioning of the ship in ice condition and open water condition. The structure of double acting ship has been improved by increasing the strength of structure to ensure the hull structure can withstand with ice resistance while break the ice.

The stem hull design of double acting ship differs from common ships. The common ships have a bulbous bow at the head of ship as shown in Figure 3. The main function of bulbous bow is to reduce the drag force that it was an effect of wave making resistance while ship moving ahead in open water. Therefore, the resistance of ship will reduce that can make increasing speed and improve stability of a ship.

The combined influence of a subsurface bulb and a conventional bow on wave formation where the wave created by the bulb cancels that created by the conventional bow is shown Figure 3. Description of the figure is as follows: profile of bow with bulb is indicated by no.1, profile of bow without bulb is indicated by no.2, wave created by bulb is indicated by no.3, waves created by conventional bow is indicated by no.4, and waterline and region of cancelled waves is indicated by no.5.

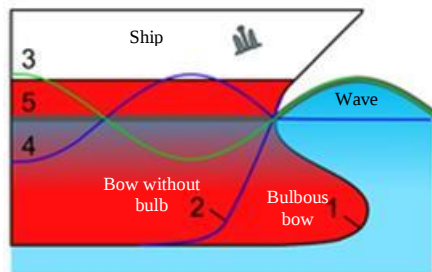


Figure 3: Bulbous bow for common tanker

By referring to Figure 3, the bulbous bow has several important advantages as follows:

1. The bulbous bow reduces the bow wave, due to the wave generated by the bulb itself
2. The ship more efficient in terms of resistance, reducing the installed power requirements and so the fuel oil consumption.
3. Works as a robust “bumper” in the event of a collision.
4. Allows the installation of the bow thrusters at a foremost position, making it more efficient.
5. Allows a larger reserve of flotation or a larger ballast capacity forward.
6. Reduces the pitch movement.

2.3. Governance Equation

Once the contact zones are spotted, the local crushing force for each zone is then calculated based on the model of average contact pressure (Riska, 1995) [29]:

$$F = P_H A_{cr} \quad (1)$$

Where; F is the local crushing force which is idealized as the product of the average contact pressure (P_H) and the contact area (A_{cr}).

Equation of State (EoS) as shown in Equation 5.1 is an equation that represents the presence of a fluid in the form of pressure and density ratios. If attention is addressed to pressure after a collision, this will become more complicated. After collision pressure will be at a high value theoretically called the peak of Hugoniot pressure.

$$p_H = \rho_0 U_s (U_0) U_0 \quad (2)$$

Where,

- p_H Hugoniot pressure
- ρ_0 material density
- U_s shock velocity
- U_0 impact velocity

After reaching the peak, pressure will decrease and the end is the stage of steady flow pressure which can be calculated using Equation 2.

$$p = \frac{1}{2} \rho_0 U_0^2 \quad (3)$$

Pressure at constant stages is easy to predict while Hugoniot pressure is also affected by shock velocity, and that is function by impact velocity too. If observed equations 1 and 2, it can be seen that pressure involved is only affected by initial density, impact and shock velocity while the impact mass unaffected by the pressure.

In this interaction review of ships with ice, ice is modeled according to linear equation of Mie-Grüneisen (Abaqus Analysis Manual 2013) [30]. This equation is also known as Us-Up equation. This Mie-Grüneisen linear equation shows a linear relationship between shock and particle velocity as shown in

Equation 3.

$$U_S = c_0 + sU_p \quad (4)$$

Where,

- c_0 speed of sound in material
- s material constant
- U_p particle velocity

So finally the relationship between pressure and density can be arranged like Equation 4.

$$p = \frac{\rho_0 c_0^2 \eta}{(1 - s\eta)^2} \left(1 - \frac{\Gamma_0 \eta}{2}\right) + \Gamma_0 \rho_0 E_m \quad (5)$$

Where,

- $\eta = 1 - \rho_0/\rho_0$ is a volumetric compressive strain
- Γ_0 material constant
- E_m internal energy in unit mass

The Mie-Grüneisen equation requires value of EOS material, and Abaqus needs ρ_0 , c_0 , Γ_0 and s . In this study, the domain is sea water so the value of $\rho_0 = 1000$ (Sea Water?), $c_0=1490$, $\Gamma_0=1.65$ and $s=1.79$, respectively (Abaqus user manual 6.13).

2.4. Time Step Iteration in Finite Element Method

Each step analysis will be divided into increments, where the size can be setting up by the user or automatically. The purpose of each increment is to find balancing point for example on a nonlinear path as shown in Figure 4.7(a). The increment will consist of several iterations. The iteration (n) in simulation will be attempted to reach the balancing point at a specific increment value. The number of iterations depends on equilibrium that can be achieved as shown in Figure 5.7(b). Sometimes the point of equilibrium cannot be achieved because iterations are divergent (Abaqus documentation 6.13).

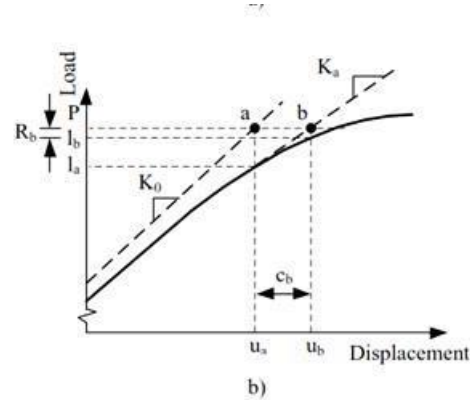
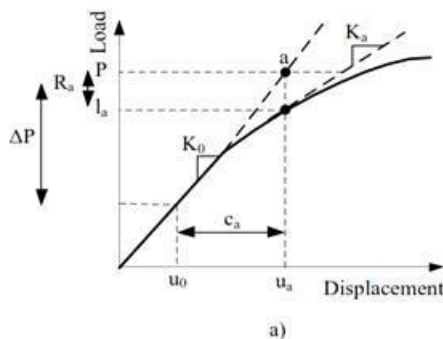


Figure 4 (a) First iteration of step (b) second iteration of step (Abaqus documentation 6.13). (Create a 'legend' on the notations used in the curves (a) and (b).

3.0 ICE RESISTANCE OF BULBOUS BOW SHIP

3.3 Modeling in Rhinoceros (Hull Surface Modeling in Rhinoceros).

FEM simulation stage starts with the making of a ship model. FEM in Abaqus has the capability to develop 2D and 3D models. However, this facility does not support irregular and complex models such as the tanker model which will be created. Stem part of the ship is made bulbous shaped for sailing in the open seas. While the stern part has a special shape because there is a section reserved to accommodate the placement of Azipods. For this reason, the Rhinoceros version-5 program was chosen in making ship models. In Rhinoceros lines and surfaces are constructed based on the mathematical model of non-uniform relational B-spline (NURBS), so that is precision for handling analytical models shapes.

In the market, there are various other packages are available than Rhinoceros which can be used for making 3D models including Solid works, AutoCAD Inventor, 3DS Max or one that is quite widely used Maxsurf for ship model design has its own advantages. While the Rhinoceros program was chosen for the design of this ship model because it has the flexibility of the arrangement of giving surfaces to curves or polylines that have been made as a 3D model base. This is very useful when making fairing job on ship design (fairing of ship hull form). Another advantage of Rhinoceros has a continuity facility which is used to analyze a joining curve before laying a surface. There are three categories results analysis of joining curve, namely G0 as Position, G1 as Tangent and G2 as Curvature. If the design model from Rhinoceros is intended to be analyzed or exported into a finite element-based program in Abaqus, the line connection must be G2, otherwise it will generate an error later. Herein lays the other advantage of Rhinoceros because this program also has facilities that will provide advice so that the connection of a line or curve is worth G2 through the command that is "Match Curve". The following are some view of ship design result from Rhinoceros such as top view, front view, right view and

perspective view before giving surface.

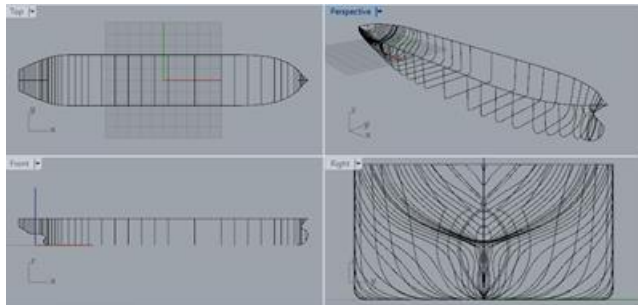


Figure 4: Top view, front view, right view and perspective view of curve design ship in Rhinoceros.

3.4 Surfaces

After giving the surface, where on this ship design involves more loft surfaces, and network of surfaces and then ship design is ready to be exported to FEA Package like Abaqus using a suitable file exchange format (.IGES). It has to be made sure that there are no overlapping surfaces and there are no surface parts that are not properly connected. This can be verified by analyzing command "Edge tool" in Rhinoceros which will inform the edge of the surface that has not been connected, namely the naked edges so that it can be repaired before being exported.

Next on the Figure 5 showing the design of ship after necessary fairing is carried out and now the ship is in full solid condition in accordance with the format required in Abaqus. To change into solid could be doing (can be done) by combining all surfaces using a join command.



Figure 5: Stern shape and bulbous at the stem part after become a solid on Rhinoceros and ready to export to Abaqus.

3.5 Domain Setting

The first thing that needs to be prepared in Abaqus is the creation of a domain in the form of water and water reference as a medium of ship working area later. Domain dimension refer to ITTC regulation 7.2-03 02-03 (ITTC 2011) as a showing in following Figure 6.

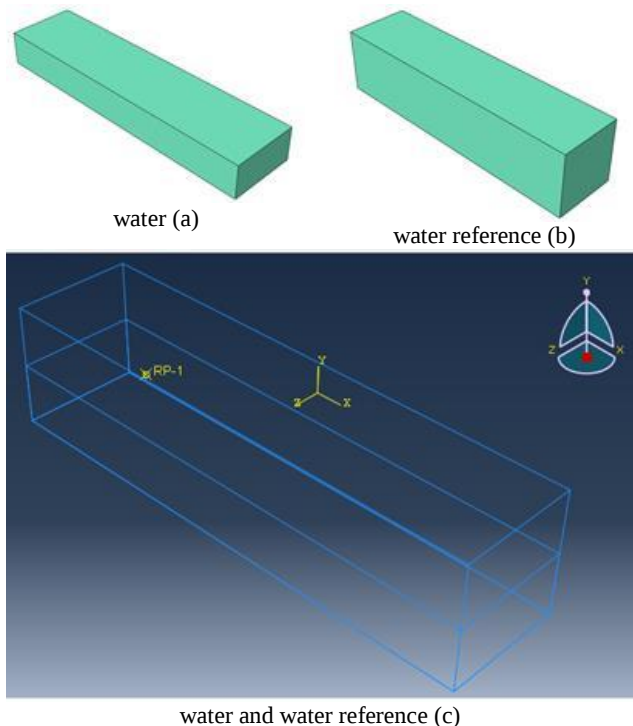


Figure 6: Fluid domain, water (a), water reference (b), assembly water and water reference (c)

2.2 Hull Modelling

In the simulation, the ship's hull is numerically modelled by spline interpolation based on information from lines drawing. When considering ship's motions in 6 DOFs, one of the important issues is to identify the waterline variation over time, given the ship's global position and orientation. This is done by searching for the intersection between the ship's hull and the water plane. Computational geometry principles (Farin, 1997) are applied to develop a subroutine to discretize the waterline into node which are updated at each time step according to the ship's current attitude. Ice is discretized into nodes too on the edge based on the ice edge shape from the previous time step or any given initial condition.

Frame angles of the waterline nodes are calculated at each time step in compliance with the ship's motions in heave, roll and pitch. In order to get information about the frame angle, ϕ , i.e., the slope angle, an extra auxiliary waterline below the instantaneous icebreaking waterline is created as shown in Figure 7 to help in constructing hull panels between the two waterlines. When the size of individual hull panel is small enough, the slope angle, ϕ , could be represented by the directional cosine between the normal to the hull, n , and vertical axis on each waterline node.

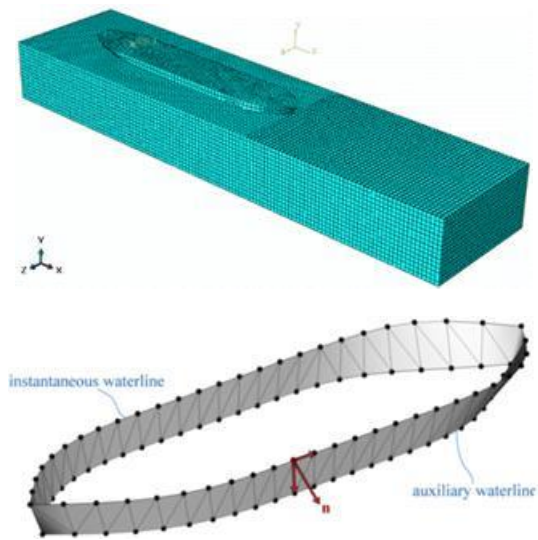


Figure 7: Frame angle calculation.

3.6 Hull-Ice Setting

After the domain is complete, next step is to import existing 3D design results from the Rhinoceros application. The design with format (.IGES) in Abaqus was converted into a Shell form first. The next step is setting several stages to avoid error in simulation process. Even if it is missing in settings, an error message will appear and simulation running process will stop immediately so that the settings need to be configured initially. Some settings are need to be done including; Positioning of the ship because vessel needs enough energy to break the ice. Other settings are the criteria of fracture conditions for the ice when interacting with ship. All of these are part of pre-processing stage in addition to other settings such as material properties, meshing, boundary conditions and others.

In position settings, ship is placed away from ice or does not come into direct contact with ice. The goal is that ship has enough energy breaking the ice. The following Figure 8 shows the position of the ship at 0s which is 1m in front of ice

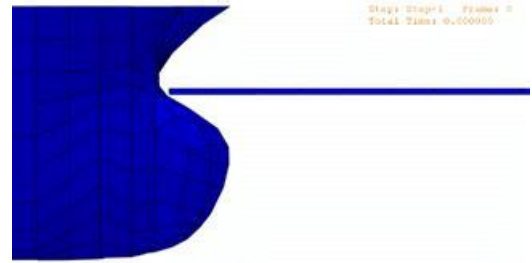
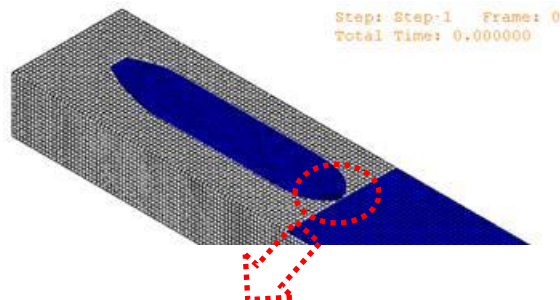


Figure 8: Placement of ship at the 1.6m distance from ice

3.7 Domain Properties

The next setting is related to properties of material in simulation. Water is defined by its density and the Equation of State (EoS) in the form of Us-Up. Then ice is also defined by its density and elasticity and the damage criterion of ice, i.e. Maximum principal stress (Maxps) with evolution failure based on displacement criteria, as shown in Figure 9

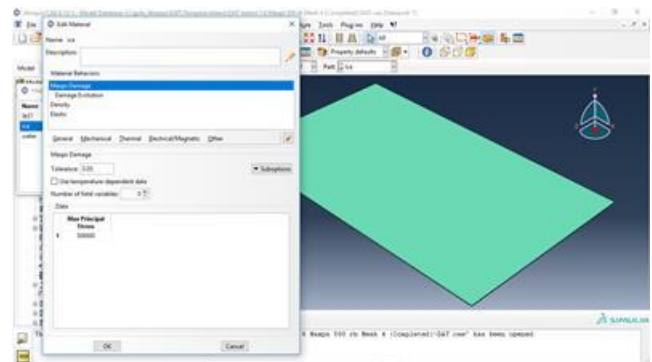


Figure 9: Tool to Select Maximum principal stress (Maxps) as output damage criterion on ice

Ship movements are designed to take place in three stages, at the beginning, Step-1 and Step-2. The purpose of grouping is to establish easy control and calculate every event in stages. For example, in the Initial stage it will start working for gravity load and made active throughout the simulation. While Step-1 is intended to calculate the interaction stage between ships and sea, while Step-2 is interaction between ships and ice. When Step-1 is run, Step-2 is active and vice versa. Property of each interaction is arranged through Interaction Properties-1 and Interaction Properties-2. While time for implementation of Step-1 is made 4s while for Step-2 is 3s

3.8 Meshing

After that, continue with generating mesh. For water and water reference, meshing by 8 node linear Eulerian type reduce integration (EC3D8R), shell type for ship, double node (S4R) and solid type 8 node for ice (C3D8R) as shown in the following Figure 10.

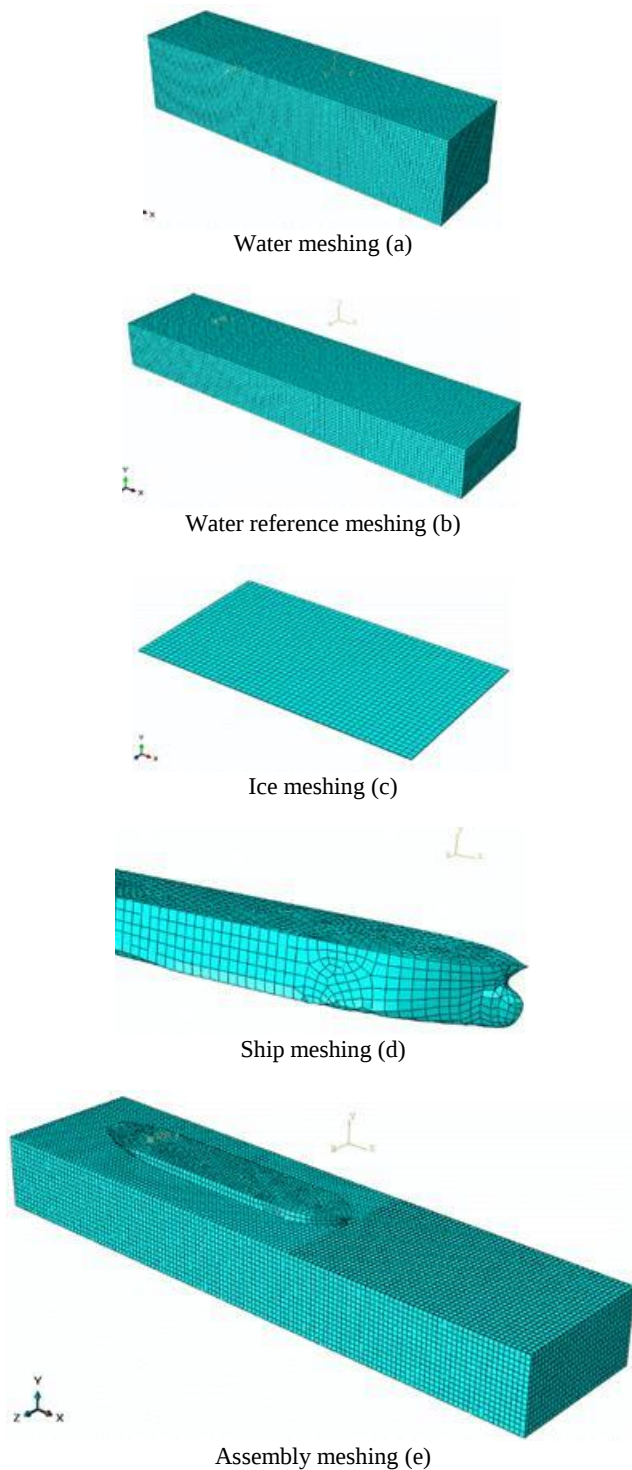
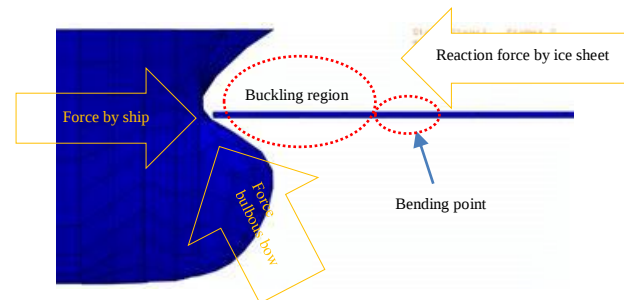


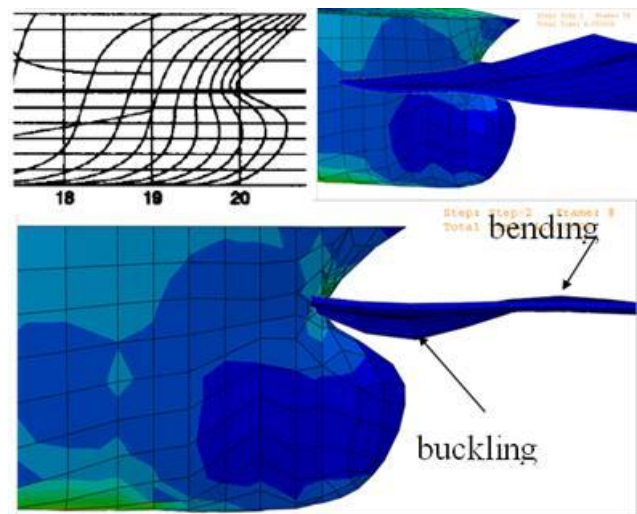
Figure 10: Generating mesh for water, water reference, ice and ship

When a ship moves to an ice field that is intact, the ship pays off the water line directly in contact with the ice cover. Since it is always the waterline that is breaking the ice, the ship's hull, especially the region around the waterline, forms the rigid body boundary condition for ice in the process of icebreaking. At the contact zones along the waterline, individual ice wedges are broken off from the unbroken ice sheet as the ship's penetration increases.

The force mechanism in the ice hull contact area is shown in Figure 11.a. In the figure, the force exerted by the ship will contradict the reaction force by the ice. The accumulation of energy around the contact area at time = t has caused buckling and bending regions as shown Figures 12 - 2. In addition, the bulbous bow gives upward force that accelerates the cause of the buckling region at around the bulbous bow. The bottom of buckling region, cracks will be occurred (occur) and growth (grow), so that water starts entering through channel of crack. Generally buckling causes the ice to split into small chunks. Slightly far from buckling, bending deformation occurs as shown in Figure 11.b.



Mechanism of force in the hull-ice contact area (a)



Bulbous bow push upward ice sheet (b)

Figure 11: Ice-bulbous bow of ship interaction.

3.0 RESULTS AND ANALYSIS

Fatigue behavior in ice is of interest for several reasons. Firstly ice in nature does experience cyclic loading is evident from field measurements. Secondly ice may be considered a ceramic. Third, when ice is used as part of a structure, such as ice bounded, the loading is frequently repetitive and may lead, through fatigue, to the degradation of the structure [Wilfrid et.al, 1993] [31]

3.2 Sailing Head 0.4m/s

Several outputs can be explored from FEM in simulation result, one of which is a reaction force. This is the force of resistance occurring on the ship during interaction with ice. FEM exhibit the results of reaction force in the form of time history during ship sailing on each of numerical iteration performed. However this result needs to be further extracted, to find the number of iterations required for the calculation to converge and time of ice breaks and value of reaction force involved. Following will be explained is a summary of the FEM iteration at 0.4m/s ship speed and 0.5m ice thickness as shown in Figure 12 – Figure 16. The main maximum force for each t is indicated in the red arrow and the crushing force for each t is indicated in the green circles. The maximum principal bending stresses to break the ice are shown at peak points 1, 2, 3, 4, and 5 as shown in the Figure 12. Before cracks occur, energy accumulates at the contact point due to two forces opposite the direction caused by the ship and ice. In addition, the growth of cracks in ice also occurs before reaching the point of failure such shown in Figure 16.

Time history of resistance in 1st iteration, at 0.4 m/s, speed

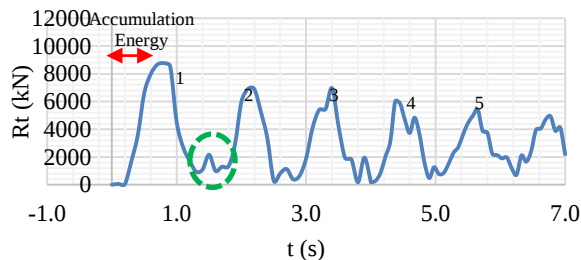


Figure 12: 1st iteration with maximum resistance force is 8766kN

Time history of resistance in 1000nd iteration, at 0.4 m/s speed

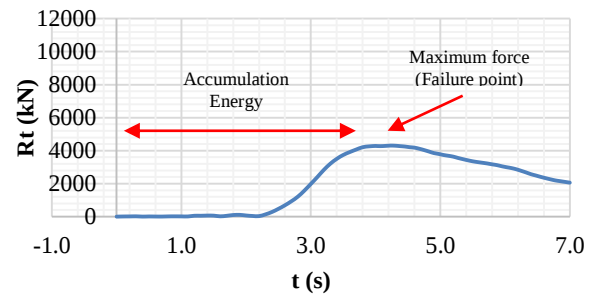


Figure 13: 1000nd iteration with maximum resistance force is 4300kN

Time history of resistance in 1500nd iteration, at 0.4m/s speed

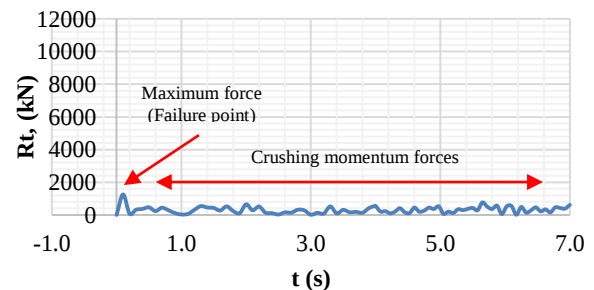


Figure 14: 1500nd iteration with maximum resistance force is 1258kN

Time history of resistance in 2000nd, at 0.4 m/s speed

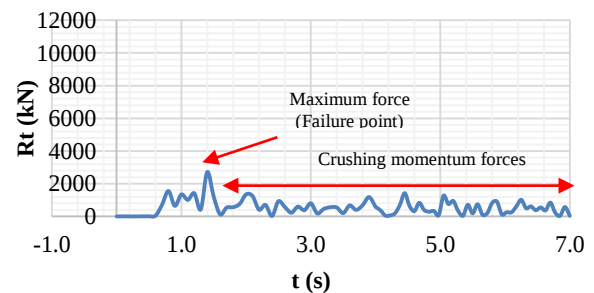


Figure 15: 2000nd iteration with maximum resistance force is 2717kN

Time history of resistance in 2650nd, at 0.4 m/s speed

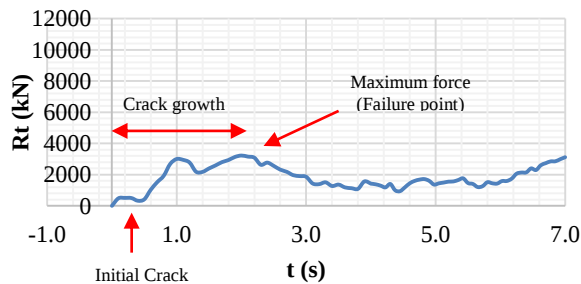


Figure 16: 2600nd iteration with maximum resistance force is 3225kN

As overall from iteration result of FEM simulation as shown in the Figure (6.19-6.23) above it can be concluded that when ship is sailing ahead at 0.4m/s on 0.5m thickness of ice conditions resistance force occurring is 3155 kN. It is known from convergence value of resistance force as shown in Figure 17. This graph shows the relationship between resistance forces to number of iterations in FEM simulations.

Ice Resistance at 0.5m ice thickness at 0.4 m/s of speed

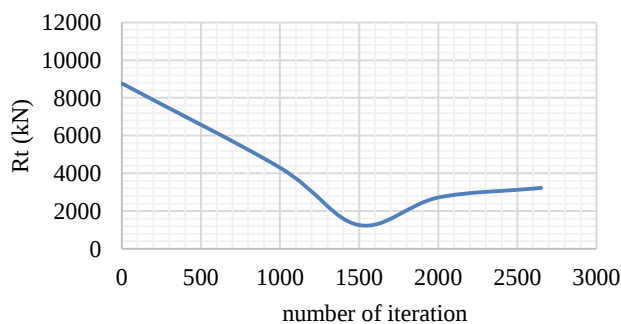


Figure 17: Resistance force related to number iteration of FEM simulation when ship sailing ahead at 0.4m/s speed.

3.2 Sailing Head 0.5m/s

The next data to be tested in FEM simulation is 0.5m/s speed of ship when sailing head on 0.5m ice thickness. The value of resistance force will be concluded after extracting resistance force result of FEM in form of time history changing to form of resistance force in iteration number as previously described. The following is a series resistance force data of FEM simulation in the form of time history as shown in Figure 18 – Figure 22. Similar to speed of 0.4 m/s, the main maximum voltage for each t is indicated in the red arrow and the crushing force for each t is indicated in the green circles. The maximum principal bending stresses to break the ice are shown at peak points 1, 2, 3, 4, and 5

as shown in the Figure 18. Before cracks occur, energy accumulates at the contact point due to two forces opposite the direction caused by the ship and ice. In addition, the growth of cracks in ice also occurs before reaching the point of failure such shown in Figure 22.

Time history of resistance in 1st at 0.5 m/s speed

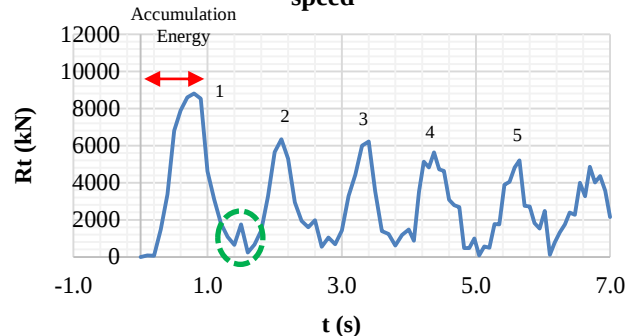


Figure 18: 1st iteration with maximum resistance force is 8800kN

Time history of resistance in 1000nd at 0.5 m/s speed

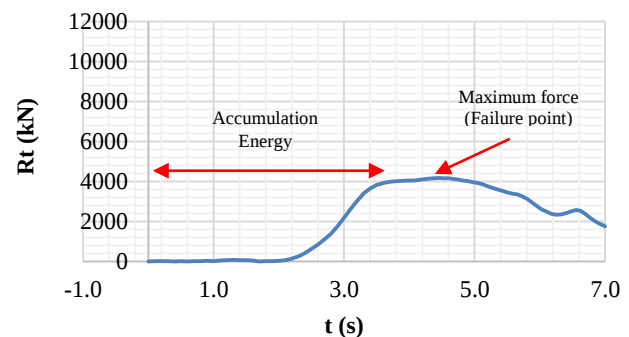


Figure 19: 1000th iteration with maximum resistance force is 4167kN

Time history of resistance in 1500nd at 0.5 m/s speed

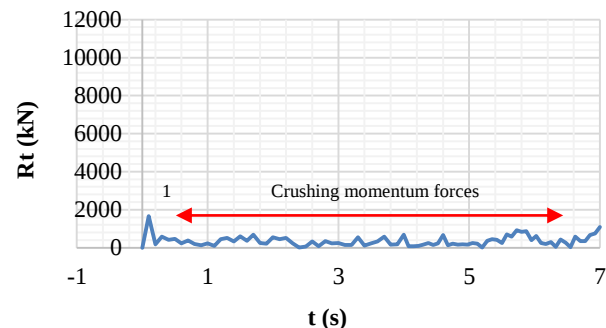


Figure 20: 1500th iteration with maximum resistance force is

1660kN

Time history of resistance in 2300nd at 0.5 m/s speed

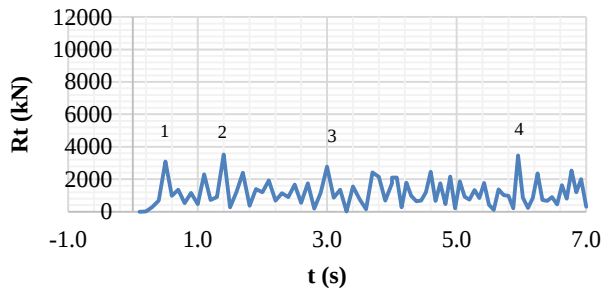


Figure 21: 2300th iteration with maximum resistance force is 3522kN

Time history of resistance in 2650nd at 0.5 m/s speed

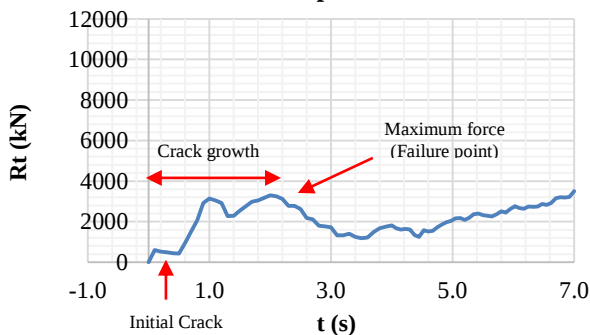


Figure 22: 2650th iteration with maximum resistance force is 3502kN

A graph can be composed as shown in Figure 6.30 below, after extracted a series data of resistance forces in time history on FEM simulation above (Figure 18 - Figure 22). This graph shows relationship between resistance force and iteration number made by FEM throughout calculation until a convergent level is reached. So the conclusion is when ship sailing ahead in 0.5m/s speed on 0.5m ice thickness it turns out resistance force of 3502 kN.

Ice Resistance at 0.5m ice thickness at 0.5 m/s speed

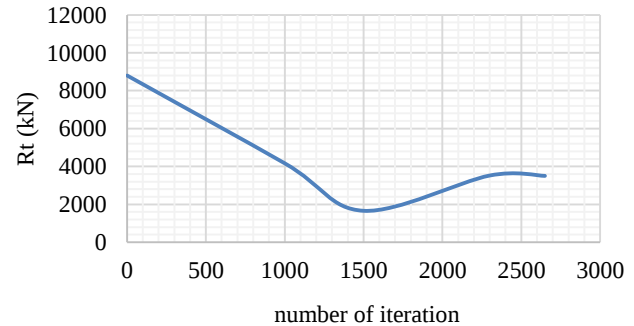


Figure 23: Resistance force related to number iteration of FEM simulation when ship sailing head at 0.5m/s speed.

8.0 CONCLUSION

In conclusion, this paper discusses effect of bulbous bow on ice resistance of ice ship using Finite Element Method based on Couple Eulerian Langrangian theory. Simulation was run at ship speeds of 0.4 m/s and 0.5 m/s at 0.5 m of ice thickness. The ice resistance increases due to buckling and bending created by bulbous bow.

ACKNOWLEDGEMENTS

The authors would like to convey a great appreciation to Ocean and Aerospace Engineering Research Institute, Indonesia and Universiti Teknologi Malaysia for supporting this research.

REFERENCES

- 1 Lewis, J.W., and Edwards, R.Y. Jr., 1970. *Methods for predicting icebreaking and ice resistance characteristics of icebreakers*. Trans. SNAME, Vol. 78, p. 213-249.
- 2 Crago, W.A., Dix, P.J., and German, J.G., 1971. *Model icebreaking experiments and their correlation with full-scale data*. Trans. RINA, Vol. 113, p. 83-108.
- 3 Enkvist, E., 1972. *On the ice resistance encountered by ships operating in the continuous mode of icebreaking*. The Swedish Academy of Engineering Sciences in Finland, Helsinki, Report No. 24, 181 pp.
- 4 Milano, V.R., 1973. *Ship resistance to continuous motion in ice*. Trans. SNAME, Vol. 81, p. 274-306.
- 5 Vance, G.P., 1975. A scaling system for ships modelled in ice. *Proc. SNAME Ice Tech. Symposium*, Montreal, Paper H1, 28pp.
- 6 Vance, G. P. (1980). "Analysis of the Performance of a 140-foot Great Lakes Icebreaker". USCGC KATMAI BAY (No. CRREL-80-8). *Cold Regions Research and Engineering lab Hanover NH*.
- 7 Lindqvist, G. (1989). A straightforward method for

- calculation of ice resistance of ships. In *Proceedings of the 10th International Conference on Port and Ocean Engineering under Artic Condition*. Lulea, Sweden.
- 8 Keinonen, A.J., Browne, R., Revill, C., Reynolds, A., 1996. *Icebreaker Characteristics Synthesis*. report TP 12812E. The Transportation Development Centre, Transport Canada, Ontario.
 - 9 Ramming and Shoulder Collisions. Transport Canada Report TP-13107E. Memorial University of Newfoundland, St. John's, Newfoundland, Canada and Helsinki University of Technology, Espoo, Finland.
 - 10 Daley, C., Tuhkuri, J., & Riska, K. (1998). The role of discrete failures in local ice loads. *Cold regions science and technology*, 27(3), 197-211.
 - 11 Jaswar, (2002). A Prediction Method of Ice Breaking of an Icebreaker, Seminar of Applied Physics, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia.
 - 12 Jaswar, (2005). Determination of Optimum Hull of Ice Ship Going. In *Proceedings of The 5th Osaka Colloquium* (pp. 139-145).
 - 13 Su, B., Riska, K., & Moan, T. (2010). A numerical method for the prediction of ship performance in level ice. *Cold Regions Science and Technology*, 60(3), 177-188.
 - 14 Jeong, S.Y., Lee, C.J., Cho, S.R., 2010. Ice resistance prediction for standard icebreaker model ship. In: *Proceedings of the Twentieth (2010) International Offshore and Polar Engineering Conference*, Beijing, China, 20-25 June 2010, pp. 1300-1304.
 - 15 Tan, X., Riska, K., & Moan, T. (2014). *Performance Simulation of a Dual-Direction Ship in Level Ice*. *Journal of Ship Research*, 58(3), 168-181.
 - 16 Tan, X., Su, B., Riska, K., & Moan, T. (2013). *A six-degrees-of-freedom numerical model for level ice-ship interaction*. *Cold Regions Science and Technology*, 92, 1-16.
 - 17 Hu, J., Zhou, L., May 2015. *Experimental and numerical study on ice resistance for icebreaking vessels*. *Int. J. Nav. Archit. Ocean Eng.* 7 (3), 626-639.
 - 18 Hu, J and Zhou, L., 2016, *Further study on level ice resistance and channel resistance for an icebreaking vessel*, *International Journal of Naval Architecture and Ocean Engineering* 8 (2016) 169-176.
 - 19 Jeong, S.Y., Choi, K, Kang, K.J and Ha, J.S, 2017, *Prediction of ship resistance in level ice based on empirical approach*, *International Journal of Naval Architecture and Ocean Engineering*, (2017) 1-11.
 - 20 Efi Afrizal, and Jaswar Koto. (2014), Study on Performance of Double Acting Tanker in Ice Condition. *The 1st Conference on Ocean, Mechanical and Aerospace*, Pekanbaru, Indonesia.
 - 21 Afrizal, E., and J. Koto. (2014). *Ice Resistance Performance Analysis of Double Acting Tanker in Astern Condition*. *Jurnal Teknologi (Sciences and Engineering)* 69.7: 73-78.
 - 22 Efi Afrizal, J.Koto, Wahid, M. A and C. L. Siow. (2016). *Review on Double Acting Tanker Ship in Ice Mode*. *Journal of Ocean, Mechanical and Aerospace*, Vol.38.
 - 23 Efi Afrizal, and J. Koto. (2016). Study on Development of Ice-Ship. *Proceeding of Ocean, Mechanical and Aerospace - Science and Engineering-*, Vol.3.
 - 24 Jaswar. Koto and Efi Afrizal, (2017). *Emperical Approach to Predict Ship Resistance in Level Ice* *Journal of Ocean, Mechanical and Aerospace*, Vol.45.
 - 25 Efi Afrizal, and Jaswar. Koto. (2017). *Analyze Performance of Double Acting Tanker while Running Astern in Ice Condition*. *Journal of Ocean, Mechanical and Aerospace*, Vol.44.
 - 26 Efi Afrizal, Jaswar Koto, Adhy Prayitno, Warman Fatra. (2018). Analysis Resistance Force on Interaction of Double Acting Tanker (DAT) –Ice using Couple Eulerian Langrangian (CEL) in Abaqus Simulation. *Proceeding of Ocean, Mechanical and Aerospace -Science and Engineering-*, Vol.5.
 - 27 Kubiak, K., (2014) *Russian Double Action Ships. Arctic Shipping Revolution or Costly Experiment*.
 - 28 Riska, K, Jalonen, R 1994. Assessment of Ice Model Testing Techniques. *Icetech 5th International Conference on Ships and Marine Structures in Cold Regions*, Calgary, Canada. SNAME.
 - 29 Abaqus theory manual 6.13 (2013): *ABAQUS theory manual*, ABAQUS 6.13 documentation, Software Manual, Dassault Systemes.
 - 30 Wilfrid A. Nixon & Larry J. Weber, 1993, *Preliminary experiments on creep crack growth in freshwater ice*, Summer Annual Meeting of the Applied Mechanics Division of ASME, June 6, pp.273-277.