Application of Euler Method on Ice Sheet Buckling

J.Koto,[a,b,*], Efi Afrizal,[a] and Wahid, M. A,[c]

[a)]*Department of Aeronautic, Automotive and Ocean Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor, Malaysia*
[b)]*Ocean and Aerospace Engineering Research Institute, Indonesia*
[c)]*Department of Thermo-Fluids, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor, Malaysia*

*Corresponding author: jaswar.koto@gmail.com, jaswar@utm.my, efi_afrizal@yahoo.com and mazlan@mail.fkm.utm.my

Paper History

Received: 20-January-2018
Received in revised form: 24-April-2018
Accepted: 30-May-2018

ABSTRACT

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 movement of the ship gradually give load to the ice sheet, along with that, the ice sheet will react in proportion to the load of the ship. Therefore the bulbous bow ship has higher ice resistance. This paper discusses the phenomena of ice sheet buckling by bulbous bow of ice ship. The ice sheet buckling was analyzed based on using Finite Element Method based on Euler method. The Euler method was described from general deflection equation for a beam.

KEY WORDS: *Bulbous Bow, Ice Sheet Buckling, Ice Ship, Finite Element Method, Euler Theory*

NOMENCLATURE

FEM	Finite Element Method
CEL	Coupled Eulerian Langrangian
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, Finncarrier, and Jelppari [3]. Milano (1973) made a significant advance in the purely theoretical prediction of ship performance on ice based on the principal of energy conservation [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 tests 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 under estimate for double acting tankers. 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 conventional bow. Researchers have proposed a Double-Acting Tanker which can sail astern functionally as an icebreaker in frozen seas and ahead in normal conditions. The stern part of DAT is specifically designed to be strong enough to break ice and pod 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 conventional bow ship sailing in ice bounded condition which is analysed using Finite Element Method.

2.0 FUNDAMENTAL OF ICE SHEET BUCKLING

2.1 Bulbous Bow

Concept of double acting ship has started developed since 1990 by Kvaerner Masa-Yards Artic 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 1. 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.

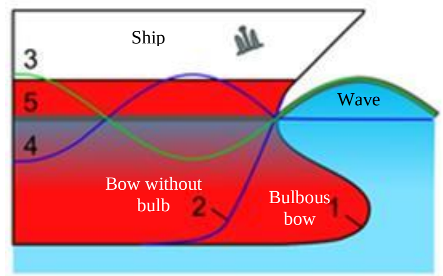

Figure 1: Bulbous bow for common tanker

By referring to Figure 1, 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. Reduction in the pitching motions.

2.2 Buckling of Ice due Bulbous Bow

Buckling is characterized by a sudden lateral deflection of structural members. It is assumed that a ship is placed away from ice or does not come into direct contact with ice. The goal is that ship has enough energy to break the ice. The Figure 2 shows the position of the ship at time at 0 second which is 1m in front of ice. The movement of the ship will gradually give load to the ice sheet, along with that, the ice sheet will react in proportion to the load of the ship. These two opposite loads are concentrated around the bulbous bow. Thus, the ice sheet will slowly buckle.

In order to explain the interaction between ice and hull, we consider a strut AB with length *L* in which the strut is applied by a compressive load, acting through its cross-sectional centroid as shown in Figure 3.

JOMAse | Received: 20-January-2018 | Accepted: 30-May-2018 | [(55) 1:11-16]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2354-7065 & e-ISSN: 2527-6085

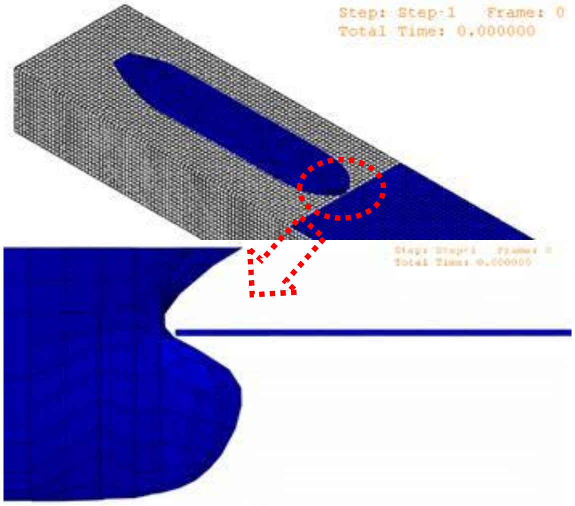

Figure 2: Placement of ship at the 1.6m distance from ice.

As the applied load (P) given bulbous bow increases in the structure, it will eventually become large enough to cause the structure to become unstable and curved before its elastic limit is reached.

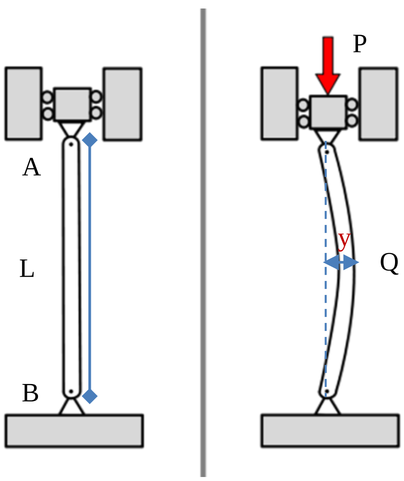

Figure 3 A Strut under a concentric axial load exhibiting the characteristic deformation of buckling.

If Q represents a section on the elastic curve of the strut and a distance x from point A, and having transverse deflection y than bending moment at section Q of the strut is

$$M = -Py \tag{1}$$

Based on the *General Deflection Equation* for a beam,

$$M = EI\frac{d^2y}{dx^2} \tag{2}$$

Therefore

$$EI\frac{d^2y}{dx^2} = -Py$$

or

$$\frac{d^2y}{dx^2} + \frac{Py}{EI} = 0 \tag{3}$$

Equation 3 is a second order linear and homogeneous differential equation,

If $\alpha^2 = \frac{P}{EI}$ or $\alpha = \left(\frac{P}{EI}\right)^{1/2}$

By substituting this expression into Equation 3 results in

$$\frac{d^2y}{dx^2} + \alpha^2 y = 0 \tag{4}$$

Equation 4 is in the form of simple harmonic differential equation. The general solution for Equation 4 can be expressed in a general statement as

$$y = A\sin(\alpha x) + B\cos(\alpha x) \tag{5}$$

Where; A and B are two constants which can be determined if the boundary conditions of the strut system are known. In this case, the two boundary conditions are

$$\begin{cases} if\ x = 0, y = 0 \\ if\ x = L, y = 0 \end{cases}$$

If the boundary conditions are substituted into Equation 5 then

$$B = 0, \text{ and } A\sin(\alpha L) = 0 \tag{6}$$

$A \neq 0$, hence, $\sin(\alpha L) = 0$

or $\alpha L = n\pi$ where $n = 0,1,2,3,4, ...$

$$\text{Then } \alpha = \frac{n\pi}{L} \tag{7}$$

From the Equation 3

$$P = \alpha^2 EI = \left[\frac{n\pi}{L}\right]^2 EI \tag{8}$$

The smallest value of this critical load is obtained if $n = 1$, that is

$$P = \frac{\pi^2}{L^2}EI \tag{9}$$

With; E is Young's Modulus of the material, I is the smallest second moment of area of strut cross section and L is length of strut.

Equation 9 is known as Euler Equation. P_{cr} is Euler critical load. If $P \geq P_{cr}$, then buckling or elastic failure will occur.

Critical buckling stress is

$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{\pi^2 EI}{AL^2} = \frac{\pi^2 EAk^2}{AL^2} = \frac{\pi^2 Ek^2}{L^2} = \frac{\pi^2 E}{(L/k)^2} \tag{10}$$

JOMAse | Received: 20-January-2018 | Accepted: 30-May-2018 | [(55) 1:11-16]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2354-7065 & e-ISSN: 2527-6085

Where; A is cross-sectional area of strut and k is smallest radius of gyration. The ratio (L/k) is called Slenderness Ratio of the strut.

2.3. Governing 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]:

$$F = P_H A_{cr} \tag{11}$$

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.

$$p_H = \rho_0 U_S(U_0) U_0 \tag{12}$$

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.

$$p = \frac{1}{2}\rho_0 U_0^2 \tag{13}$$

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.

$$U_S = c_0 + sU_P \tag{14}$$

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.

$$p = \frac{\rho_0 c_0^2 \eta}{(1 - s\eta)^2}\left(1 - \frac{\Gamma_0 \eta}{2}\right) + \Gamma_0 \rho_0 E_m \tag{15}$$

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 needsρ_0, c_0, Γ_0 and s. In this study, the domain is sea water so the value of ρ_0 = 1000, c_0=1490, Γ_0=1.65 and s=1.79, respectively (Abaqus user manual 6.13)

3.0 FUNDAMENTAL OF ICE BREAKING

3.1 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.

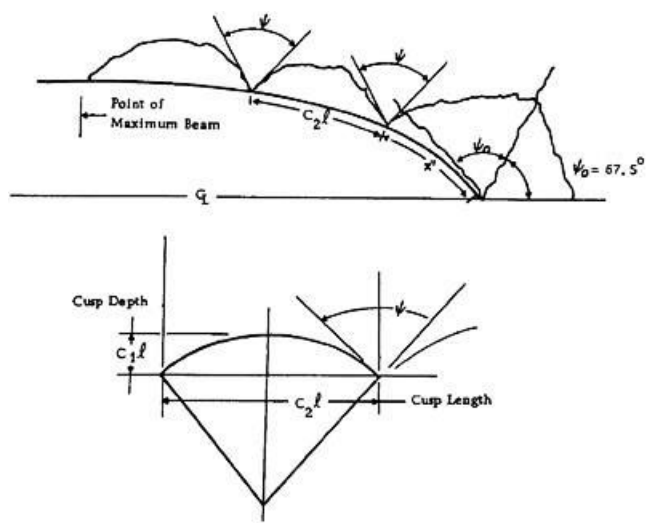

Figure 1: Idealized bending model of icebreaking (l denotes the characteristic length of ice) (Milano, 1973) [4].

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

 JOMAse | Received: 20-January-2018 | Accepted: 30-May-2018 | [(55) 1:11-16]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2354-7065 & e-ISSN: 2527-6085

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 $time = t + dt$ are shown at points no 7, 8, 9 and 10.

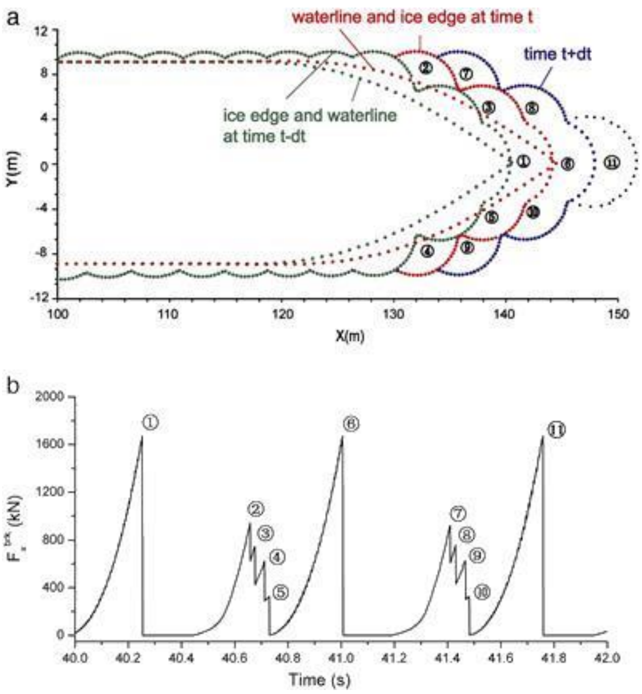

Figure 2: Ice–ship interaction and corresponding breaking force (Tan et.al 2013) [15].

3.2. Time Step Iteration in Finite Element Method

Each step analysis will be divided into increments, where the size can be setup by the user or automatic time setup can also selected. 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 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).

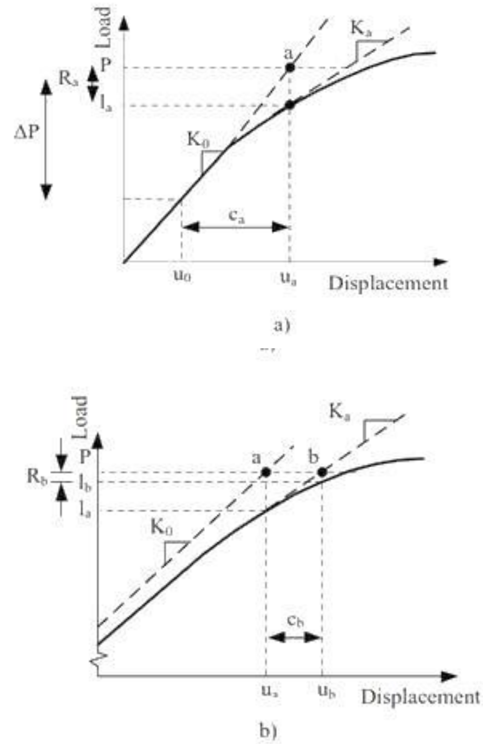

Figure 4 (a) First iteration of step (b) second iteration of step (Abaqus documentation 6.13).

5.0 CONCLUSION

In conclusion, this paper discusses the phenomena of ice sheet buckling due to bulbous bow of ice ship in level ice. The ice sheet buckling was described based on Finite Element Method based on Euler theory from general deflection equation for a beam.

ACKNOWLEDGEMENTS

The authors would like to convey a great appreciation to Ocean and Aerospace Engineering Research Institute, Indonesia and Universiti Teknologi Malaysia, Skudai, Johor, 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 Goin, *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*.
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). *Empirical 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 Kubiak, K., (2014) *Russian Double Action Ships*. Arctic Shipping Revolution or Costly Experiment.
27 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.
28 Abaqus theory manual 6.13 (2013): ABAQUS theory manual, ABAQUS 6.13 documentation, Software Manual, Dassault Systemes.
29 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.