Ocean Engineering 92 (2014) 12–19

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Development of estimation system of ice resistance with surface information of hull form

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ARTICLE INFO

Article history:
Received 30 September 2013
Accepted 28 September 2014

Keywords:
Ice resistance
Clearing plane
Resistance estimation
Surface information
Ice model test

ABSTRACT

At the initial stage of an ice breaking ship design, a reliable empirical estimation of ice resistance is important to determine the power of the ship. In this study, a prediction method with three dimensional surface information of the ship is presented. The idea is from the existing empirical formula where two-dimensional approach is prevailed. This paper modifies the definition of the hull form with three-dimensional surface information to increase the accuracy. A clearing plane, vector d, the curl between vector p and vector n is adopted. Vector p is the curl between normal vector n at the design load water line and vector i of the ship in the forward direction. A tangential angle is extracted from the vector d and applied to the empirical method. Piece size of broken ice is assumed to be same as the hull form grid and taken in calculation of the clearing force of ice. In the estimation system, a graphical user interface is adopted for easy handling of the relevant data files. Comparison between model test and calculation is provided to validate the system and it is found that the difference is 15% maximum for a hull with a twin-podded system.

1. Introduction

Recently in Korea, ice or arctic engineering has been a rapidly expanding research field. Infra-structures such as ice model basin (2009) and ice breaking research vessel *Araon* (2010) are good examples of interest in arctic engineering (Kim and Lee, 2010; Lee et al., 2006; Kim et al., 2011b). Several results of ice sea trial and measurement of ice properties on the Arctic Sea and near the Antarctic Sea are already published and commercial ice model tests for a large ice breaking vessel are under preparation (Lee and Jeong, 2011; Kim et al., 2011a; Choi et al., 2011).

Meanwhile, hull form design is one of the major parts as in ice technology and consequently, the estimation of ice resistance is of great interest to the shipbuilding company and researcher with regard to ice performance. Estimation of ice resistance in the concept and basic design stages is the important step because it is the starting point to calculate the engine capacity of the vessel. Thus, accuracy of the estimation method is critical to hull form design. Hull form designers wish to know exact ice resistance when the hull form of a vessel is decided. The final goal of the designer is to find the optimum hull form for given design constraints. These constraints include maximum engine size, engine capacity and target cargo capacity based on economic analysis.

To determine the capacity of the engine in the early stage, empirical formulas are often used to calculate the resistance of the ship. However, from time to time, empirical formulas show differences in resistance because several parameters in the formulas are based on the results of ice model tests. Even existing formulas yield large differences depending on the type and size of ship. Especially, a large cargo carrier for the arctic regions which has no bulbous bow and a complicated stern shape, two or three propulsions systems, is an example when compared with the results of ice model test. To enhance the accuracy of ice resistance estimation for such large ice breaking vessels, some useful empirical formulas are revisited in this study such as Shimanskii (1938), Enkvist (1972), and Poznyak and Ionov (1981).

The hull form of Double Acting Ships or DAS, W-shaped in sectional view as shown in Fig. 2, is the most difficult case to apply the empirical formulas to calculate ice resistance especially, when the vessel is going astern, because in the formulas, the integration of section and waterline with regard to the angle at the end point of design load water line or DLWL (where the angle closes to 90°) does not converge.

To solve this problem, a modified scheme of calculation for ice resistance is investigated. The calculation results for a large ice breaking vessel are shown and compared to ice model tests in this paper.

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http://dx.doi.org/10.1016/j.oceaneng.2014.09.038
0029-8018/

The assessment of the calculation scheme developed for ice resistance is discussed as well.

2. Modification of scheme for estimation of ice resistance

2.1. Coordinate system and restriction of empirical formula

The x, y, z coordinate system is the same as the conventional coordinate system in naval architecture, i.e., the x-axis is longitudinal from A.P to F.P, the y-axis is athwartship from starboard to port and the z-axis is vertical from bottom to deck. Fig. 1 shows the coordinate system adopted in this study. Angle α is defined as an angle between the x-axis and the tangent line of water line at an arbitrary point or "node" in the x–y plane, angle β is an angle between the z-axis and the tangent line of a section at a node in the y–z plane. Angle γ is an angle between the z-axis and the tangent line of a buttock at a node in the x–z plane. Vector $\vec{n}$ is the normal vector at a node point of the hull surface. Angle ϕ is the bow angle in profile view. In the case of DAS, the geometry in the stern part is complicated so that the angle α is well over 90° in-between the mounts for the propulsor units. In such a case, it is impossible to calculate the formula because the ice resistance has a negative value in Eq. (5) when angle α is greater than 90°.

In this study, the stern section is split into two parts – inside and outside – based on the angle α of 90°. The inside part is in-between the two pods and the outside one is outside the pods in the y-axis direction as shown in Fig. 2 (straight diagonal in red divides the section). This approach makes it possible to calculate the ice resistances of breaking, buoyancy and clearing in the complicated hull form of W-shaped section.

2.2. Estimation of breaking resistance

Shimanskii (1938) defined an ice breaking parameter and an ice cutting parameter based on the forces acting on the x, y, z directions. The relationship between thrust and breaking force defines the ice breaking parameter. He employed a simple hull form and there are no empirical parameters or coefficients. In this study, the same coordinate system is used but adds another definition of the angle in the x–z plane as shown in Fig. 1. Shimansky also defined forces acting on the x-, y-, z-axis as F_x, F_y and F_z respectively in unit beam. The formulas are shown below:

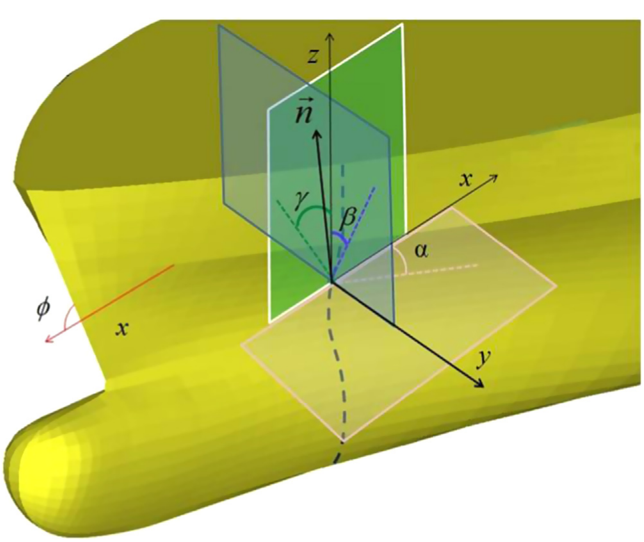

Fig. 1. Coordinate system employed.

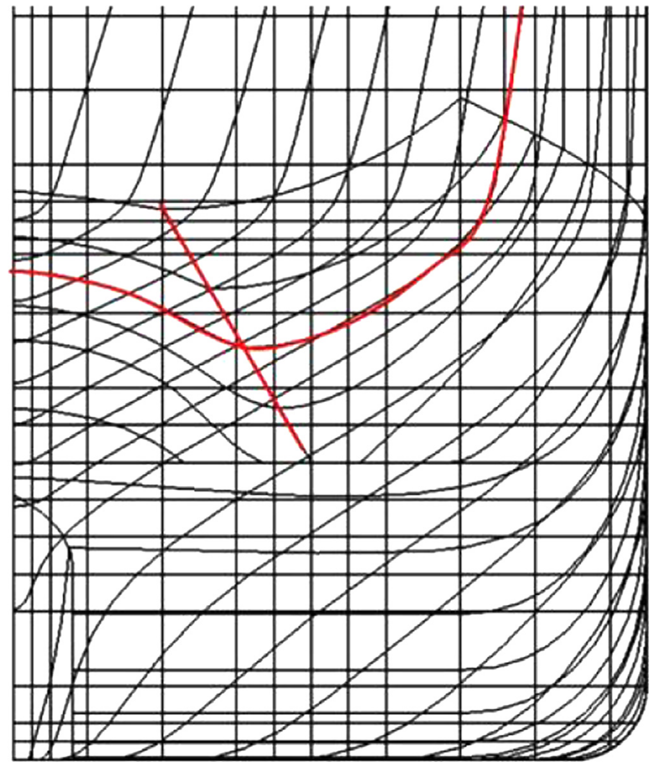

Fig. 2. Section view of W shape hull and splitting line. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

$$F_x = \int_0^{L_E} \frac{\tan^2\alpha \cdot \sqrt{1+\tan^2\alpha}}{1+\tan^2\alpha+\tan^2\beta}\,dx \quad (1)$$

$$F_y = \int_0^{L_E} \frac{\tan\alpha \cdot \sqrt{1+\tan^2\alpha}}{1+\tan^2\alpha+\tan^2\beta}\,dx \quad (2)$$

$$F_z = \int_0^{L_E} \frac{\tan\alpha \cdot \tan\beta \cdot \sqrt{1+\tan^2\alpha}}{1+\tan^2\alpha+\tan^2\beta}\,dx \quad (3)$$

where L_E is the length from fore end to maximum beam of ship.

He also defined thrust as shown in Eq. (4) for unit beam:

$$T = \frac{\lambda \cdot \sigma_f \cdot h^2}{1.93} \cdot \frac{1}{\eta_1} \quad (4)$$

where $\lambda = \sqrt[4]{3\rho_w g/Eh^3}$, $\eta_1 = F_z/F_x$ is the ice breaking parameter, g is the gravitational acceleration, h is the ice thickness, E is Young's modulus of sea ice, and ρ_w is the water density.

Since the breaking resistance for the unit beam is equivalent to thrust in Eq. (4), the breaking resistance is then calculated by the multiplication of the y value at each of the nodes using Eq. (4). This method has no empirical parameters but only uses geometrical informations of the hull form and the properties of ice.

In the case of a W-shaped hull, the calculation of ice breaking resistance is carried out accordingly after splitting the hull form into two or three based on the variation of angle α. The input files for the hull form are split and automatically generated as different allocated names when the angle α reaches 90° and 180°. Total ice resistance is then sorted after all the calculations even though the input files are split.