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Prediction of ship resistance in level ice based on empirical approach

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Abstract

A semi-empirical model to predict ship resistance in level ice based on Lindqvist's model is presented. This model assumes that contact between the ship and the ice is a case of symmetrical collision, and two contact cases are considered. Submersion force is calculated via Lindqvist's formula, and the crushing and breaking forces are determined by a concept of energy consideration during ship and ice impact. The effect of the contact coefficient is analyzed in the ice resistance prediction. To validate this model, the predicted results are compared with model test data of USCGC Healy and icebreaker Araon, and full-scale data of the icebreaker KV Svalbard. A relatively good agreement is achieved. As a result, the presented model is recommended for preliminary total resistance prediction in advance of the evaluation of the icebreaking performance of vessels.

Keywords: Semi-empirical model; Ship resistance; Level ice; Breaking force; Icebreaking performance

1. Introduction

Determining ice resistance is more complicated than determining open water resistance due to the characteristics of ice properties and icebreaking phenomena. The prediction of icebreaking performance and resistance in level ice is a fundamental area of research; consequently, many researchers have focused on ship—ice interaction. In order to calculate a ship's resistance in ice, analytical and empirical approaches have been proposed. Lindqvist (1989) presented a relatively simple empirical formula in which the model is a function of the main particulars of the ship, hull form, ice thickness, ice strength, and friction. Lindqvist considered a wedged bow shape and divided ice resistance into three parts: crushing, bending, and submersion. Riska et al. (1997) also studied ice resistance prediction. Their model can be used for calculating resistance in level ice, with the empirical coefficients being derived from the full-scale data of a number of ships in the Baltic Sea. The concept of energy consideration has also been introduced to estimate the ice force of a ship. Daley (1999) considered the relationship between indentation energy and kinetic energy and proposed various analytical formulas with which to calculate ice collision forces. This method can predict the ice force for several geometric cases. Spencer and Jones (2001) investigated methods of predicting ice resistance and proposed a component-based ice resistance prediction method, which assumed that four different resistance force terms occur during an icebreaking procedure. These forces can be divided into open-water resistance, buoyancy resistance, clearing resistance, and breaking resistance. This method is used in Canada's National Research Council Canada-Ocean, Coastal and River Engineering (NRC-OCRE former NRC-IOT) ice model basin to determine the ice resistance for various model-scale and full-scale icebreaking vessels. Recently, numerical approach has been introduced to evaluate the manoeuvring performance of ship in ice. In particular, Liu et al. (2006) developed a numerical model to simulate a ship's maneuvering performance in

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ice. Su et al. (2010) proposed a numerical model based on the Lindqvist's model to calculate the ship motion and resistance in level ice condition as well. They considered the rudder and propeller forces, hydrodynamic force and ice force in the ship resistance calculation. In addition, Aksnes (2010) and Lubbad and Loset (2011) studied on the ship and ice interaction and developed a numerical model, respectively.

In this study, a semi-empirical method for ship resistance prediction in level ice based on Lindqvist's model is introduced and a simplified model is presented. This model assumes that ship and ice contact is a case of symmetrical collision, and two contact cases are considered. During the contact between ship and ice, the submersion force is determined by Lindqvist's formula and the crushing and breaking forces are determined by a concept of energy consideration. The accuracy of ice resistance prediction is confirmed by model test data of the icebreakers *Healy* and *Araon* and full-scale data of the icebreaker KV *Svalbard*.

2. Ice resistance of a ship

The total resistance in ice is the sum of two components, such as the open-water resistance and the ice resistance (ITTC, 2005). In particular, open water resistance is obtained from the towed model test in calm water, and ice resistance is obtained from subtracting the open water resistance from the total resistance in ice. The total resistance in ice can be determined as:

$$R_{tot} = R_{ice} + R_{ow} \tag{1}$$

where R_{tot} is total resistance in ice, R_{ice} is ice resistance, and R_{ow} is open-water resistance.

To determine the ice resistance, crushing due to ship and ice contact, breaking and submersion of broken ice pieces after breaking should be considered. In particular, the breaking force comprises a large proportion of total resistance in ice; thus, the breaking component is a significant parameter in the prediction of ice resistance. Fig. 1 shows crushing, breaking, and submersion phenomena in the model test. When an icebreaker model enters an ice sheet, crushing occurs at the stem and continues to increase at the contact area until bending failure of the ice sheet. After bending failure, the broken ice pieces can be rotated and submerged along the ship bottom, and this cycle is repeated during the icebreaking procedure.

Ice resistance can be divided into crushing, bending, and submersion (buoyancy and frictional forces). In particular, Lindqvist's model assumes that the ice resistance R_{ice} increases linearly with ship speed, and the empirical constants in the velocity term are used to calculate the total ice resistance. In Lindqvist's model, ice resistance depends on the following variables:

$$R_{ice} = f\{R_c, R_b, R_s\} \tag{2}$$

The failure mode of an ice floe is divided into two alternative phases, crushing–shearing and crushing–bending, and is related to the ship and ice contact area. During an icebreaking procedure, if the force derived from the contact area is less than what would cause bending failure of the ice, the failure mode of the ice floe is composed of the crushing and the shearing phases, but when the force derived from the contact area is sufficiently large, bending failure occurs in the ice floe. After bending failure, broken ice pieces are submerged under the ship's bow and bottom, causing a friction force against the ship. The calculation of the ship and ice contact area is an important aspect of this study. Thus, to determine the projected contact area after impact, the ice floe is assumed to be level ice and the case of ship and ice contact regarded as a symmetrical (head-on) collision. This

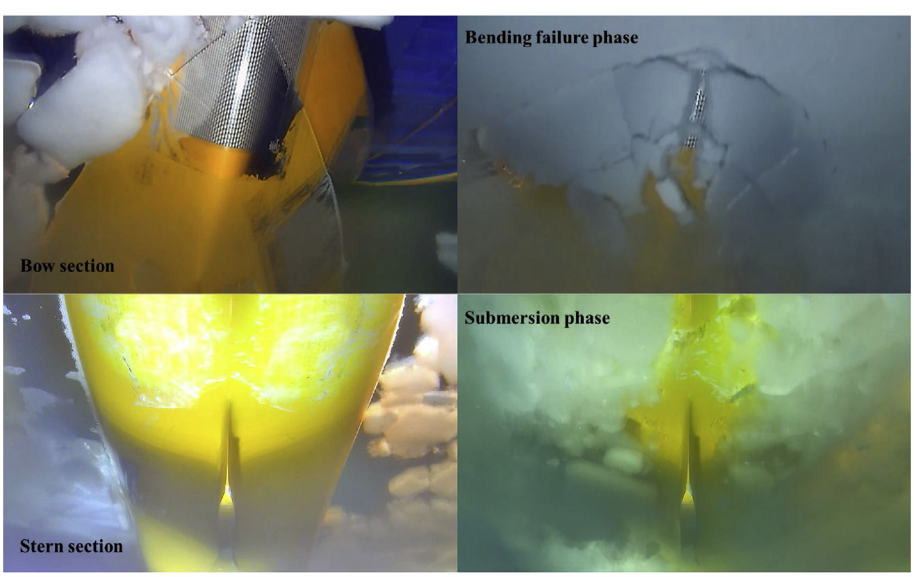

Fig. 1. Ice breaking phenomena in the model test (Jeong et al., 2014).

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