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Calculation of ice clearing resistance using normal vector of hull form and direct calculation of buoyancy force under the hull

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ABSTRACT: *The ice-resistance estimation technique for icebreaking ships had been studied intensively over recent years to meet the needs of designing Arctic vessels. Before testing in the ice model basin, the estimation of a ship's ice resistance with high reliability is very important to decide the delivered power necessary for level ice operation. The main idea of previous studies came from several empirical formulas, such as Poznyak and Ionov (1981), Enkvist (1972) and Shimansky (1938) methods, in which ice resistance components such as icebreaking, buoyancy and clearing resistances were represented by the integral equations along the Design Load Water Line (DLWL). The current study proposes a few modified methods not only considering the DLWL shape, but also the hull shape under the DLWL. In the proposed methodology, the DLWL shape for icebreaking resistance and the hull shape under the DLWL for buoyancy and clearing resistances can be directly considered in the calculation. Especially, when calculating clearing resistance, the flow pattern of ice particles under the DLWL of ship is assumed to be in accordance with the ice flow observed during ice model testing. This paper also deals with application examples for a few ship designs and its ice model testing programs at the AARC ice model basin. From the comparison of results of the model test and the estimation, the reliability of this estimation technique has been discussed.*

KEY WORDS: Ice; Resistance; Empirical formulas.

INTRODUCTION

The first Korean ice breaker was built and tested in the Arctic (Kim et al., 2011) and a number of projects related to the transportation of natural resources by icebreaking ships from or through the arctic region have been carried out recently, and a few of them are still under development stage.

Unlike normal ships operating in ice-free waters, for an icebreaking ship, the designers need to primarily consider the icebreaking capability of the ship and most importantly, designing a hull form of the ship. The hull-form design has been one of major parts of ice technology, and thereby, an estimation of the ice resistance is an important issue to both the shipbuilding companies and the researchers.

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The final goal of the ship designer is to find the optimum hull form for a given set of design parameters, such as the maximum engine size and capacity and target cargo capacity based on economic analysis.

During the concept and basic design stage, estimation of ice resistance induced by the hull form is an important step because it is the starting point of the calculation of the engine capacity.

For the estimation of ship resistance in ice, three methods are normally used, which are as follows:

1) Ice test in the ice model basin
2) Empirical formulas based on the parameters of a ship
3) Numerical simulation

Ice test in the ice model basin is the most reliable method to predict a ship's ice resistance as well as its powering performance in ice. However, the ice test is not a practical approach during the concept and the basic design stage because of the high cost and long testing time. Another alternative to this ice test is numerical simulation; however, such approach is still in its beginning stage. In this regard, empirical formulas based on the parameters of an icebreaking ship, thus seem to be a more practical and useful approach.

However, the empirical formulas may give large differences depending on the types and sizes of the ships because the published formulas used several parameters that were based on ice model test results for small sized icebreakers. Especially, for large cargo ships in the arctic region, the results of the empirical formulas are likely to show a larger difference than those of the ice model test.

To increase the reliability of the estimation scheme for large icebreaking ships, some useful published empirical formulas of Poznyak and Ionov (1981), Enkvist (1972) and Shimansky (1938) have been studied in this paper because those formulas were formulated reflecting the hull form geometry.

The ice resistance in most of the empirical formulas is generally comprised of three components, viz. icebreaking, buoyancy and clearing resistances, which are represented by the integral equations along the DLWL. In this regard, the current study proposes some modified methods considering not only the DLWL shape, but also the hull shape under the DLWL to increase the reliability of the ice resistance estimation.

The hull form of Double Acting Ships (DAS) can have either a "double V shape (VV)" or a "triple V shape (VVV)" in section of stern. To this V shapes, it becomes complicated to directly use any published formula because the integrand function diverges when clearing angle along the DLWL becomes close to 90 deg. To address this problem, a new way of calculation of the clearing resistance has been proposed in this study.

The current paper also deals with the application examples and its ice model testing programs at AARC ice model basin. From the comparison of results between the model test and theoretical estimation, the reliability of this estimation technique has been evaluated.

SCHEME FOR ICE RESISTANCE ESTIMATION

Definition of angles

The direction of x-axis is followed by length of ship from After Perpendicular (AP) to Fore Perpendicular (FP), the direction of y-axis is heading from center line to port side and the direction of z-axis is from bottom of ship to deck.

Fig. 1 shows definition of angles. Angle α is defined as the angle between the x-axis and the tangent of waterline at an arbitrary point in the x-y plane, angle β is the angle between the z-axis and the tangent of section line in the y-z plane and angle γ is the angle between z-axis and tangent line of buttock line in x-z plane. Vector $\vec{n}$ is the normal vector at an arbitrary point of hull form. Angle ϕ is the stem angle in profile view.

In case of 'double or triple V shape' for DAS, the geometry is divided into two or three parts, such as the inside and the outside to calculate the ice resistance separately, as shown in Fig. 2.

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