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Time domain simulation for icebreaking and turning capability of bow-first icebreaking models in level ice

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Abstract

Recent icebreaking ships need to be designed to enhance not only icebreaking capability but also turning ability. For the evaluation of ice resistance induced by an icebreaking hull form, HHI (Hyundai Heavy Industries) has developed the hybrid empirical formulas (Park et al., 2015) by considering the geometrical hull shape features, such as waterline and underwater sections. However, the empirical formulas have inherent limits to the precise estimation of the icebreaking and turning ability because the breaking process and the resulting pattern are ignored. For this reason, numerical calculation in time domain is performed to predict the icebreaking process and pattern. In the simulation, varying crushing stress according to velocity vectors and contact areas between hull and ice is newly introduced. Moreover, the simulation results were verified by comparing them with the model test results for three different bow-first icebreaking models.

Keywords: Ice resistance; Icebreaking and turning capability; Empirical formulas; Level ice

1. Introduction

Recently, Hyundai Heavy Industries (HHI) has been involved in many projects relating to the transportation of natural resources by icebreaking vessels from or through the arctic region, starting from the hull form development for a 190,000 dwt class arctic ore carrier (Park et al., 2011). For icebreaking ship design, it is essential to know how to evaluate and minimize the ice resistance as well as to confirm whether the ship satisfies the specific requirements, such as minimum icebreaking speed and turning ability given the ice conditions and the engine power.

For the evaluation of ice resistance, several empirical formulas have been introduced by many researchers, but the typical method proposed by Lindqvist (1989) has been widely used among ice model basins and ship yards. This method uses the basic hull information such as length, breadth, depth, hull angles, etc. Recently HHI had developed the hybrid methods (Park et al., 2015) to get a relatively high level of accuracy by considering geometrical hull shape, such as waterline at Design Load Water Line (DLWL) and underwater hull sections. In detail, ice resistance was assumed to comprise of three components: breaking, clearing and buoyancy resistances. The Shimanskii icebreaking resistance (1938), the Enkvist buoyancy resistance (1972) and the newly modified clearing resistance from Ionov (Poznyak and Ionov, 1981) were combined.

However, the empirical formulas have inherent limits to precise estimation of the icebreaking and turning ability because the icebreaking process and its pattern are ignored. That is, although the empirical formulas give a certain level of accuracy in ice resistance estimation, Shimanskii's formula does not consider the icebreaking process and its pattern around the ship's shoulder in sufficient detail, so it is not appropriate to use when judging the quality of the ship's turning ability.

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On the other hand, Su (2011) suggested a time-domain numerical simulation method based on an icebreaking procedure with constant crushing stress. This method well represents the icebreaking patterns and estimates the turning ability of icebreaking ships. In addition, it shows a good agreement with full scale measurements for a small size icebreaker shown by Riska et al. (2001). Through this study, the authors tried to apply this technique to commercial icebreaking ships and checked whether it is suitable for the estimation of icebreaking patterns and turning capability or not.

However, it was found that the commercial icebreaking ships typically have long parallel middle body, so the ice resistance in time domain simulation increases dramatically due to the constant crushing stress around this area. Therefore, a new method with varying crushing stress is proposed to avoid the problem. In this study, the crushing stress is assumed to vary with not only the contact area between hull and ice (Ashby et al., 1986) but also the linear velocity vector and the angular velocity vector of ship. Moreover, its applicability to ice resistance estimation for three different bow-first icebreaking models is tested comparing with the results of model tests. For the simulation of ship motions, the modular type mathematical model with multiple POD propulsors (Kim et al., 2006) is used.

2. Numerical simulation

2.1. Varying crushing stress

Ice resistance is comprised of three parts: breaking, buoyancy and clearing parts. This study is mainly focused on the breaking part in the numerical simulation, and the others are simply treated by the empirical formulas of Lindqvist (1989). The overall process of the numerical simulation is denoted by the flow chart in Fig. 1.

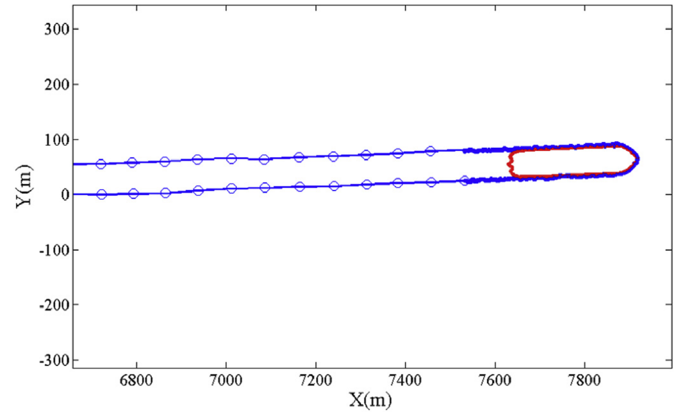

Fig. 2. Description of ice nodes generation.

Initial inputs are hull and ice information such as waterline shape, propeller open water characteristics and ice properties. The waterline of the hull and ice are marked in discretized nodes as shown in Fig. 2. As a ship moves forward, the contact area between the hull and ice is calculated, and whether its vertical load exceeds the bending failure load or not is checked according to the same logical process proposed by Su (2011). If bending failure occurs, the ice geometry is regenerated and then the forces and moment acting on the ship are calculated. During the process, the nodes which are not in contact with hull are excluded from the calculation to enhance the computational efficiency and the number of ice nodes in the far field from hull is reduced to avoid a waste of memory.

Su (2011) proposed using the constant crushing stress to calculate ice load in level ice, but it was found that this constant value makes the ice load increase sharply around the long parallel middle body of ship. To solve this problem, the concept of varying crushing stress defined by the contact area between hull and ice is newly introduced in this study.

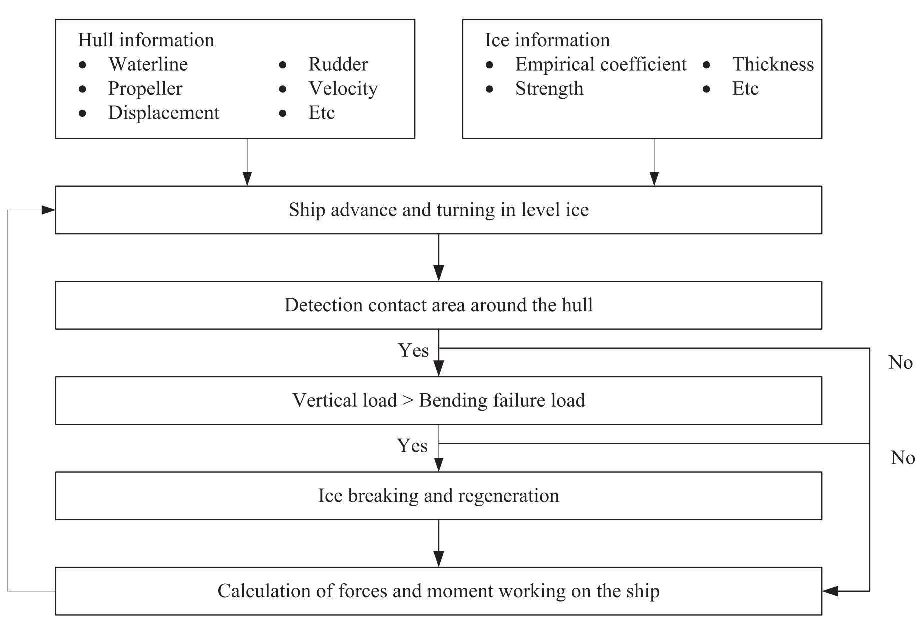

Fig. 1. Flow chart of numerical simulation.