Ice Resistance Prediction of an Icebreaker based on Nonlinear Finite Element Method

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ABSTRACT
In this paper, the numerical model of ice is established based on nonlinear finite method, and the process of damage is simulated by means of the computational cohesive element model. The gravity, buoyancy and drag force are added to the motion equations of ice blocks to establish the ice resistance prediction method. Then an icebreaker sailing in level ice is simulated and the phenomena of the ice blocks including rolling over in the water and sliding on the hull are obtained. It shows that a positive correlation between ice resistance and speed, then resistance-speed linear curves are generated to analyze the influences of ship speed and ice thickness on the ice resistance.

KEY WORDS: Icebreaker; Resistance Prediction; Level Ice; Nonlinear Finite element; Flexural strength; Compressive strength.

INTRODUCTION
With the global warming and the melting glaciers, the development of resource and shipping routes in Arctic have become possible. Polar transport or engineering ships with certain ice-breaking capabilities will play an important role in the development of polar resources. In the design process of such ships, ice resistance prediction provides an important input for ship ice breaking capacity and power demand analysis, which is also one of the key links in the overall design. In terms of ship ice resistance prediction, the main methods include model test, empirical formulas and numerical simulation. Model test is the most reliable method, and the empirical formulas based on statistical analysis such as Lindqvist method(Lindqvist G. 1989), Keinonen method(Keinonen A et al. 1991), Jeong method(Jeong S Y et al. 2010), Riska method(Riska K et al. 1997), Spencer method(Devi et al. 2001) are rapid methods, which are widely used in the ice resistance prediction. Numerical simulation can take into account the effects of sea ice damage modes and more ship form information to predict ice resistance compare to empirical formula, and its cost is much less than model test. The finite element method is one of numerical simulation methods, which is commonly used to research the numerical model of ice and predict the ice load and ice resistance of ships during ice-breaking navigation.

Yang L et al. (2008) adopted the method of fluid-structure interaction and established the nonlinear finite element model of collision between ship and ocean platform by taking sea ice as medium. Wang B et al. (2008) developed a collision model of crushable ice based on nonlinear dynamic finite element and analyzed the ice load of a FLNG ship using commercial code DYTRAN. Gürtner A et al. (2009) used the numerical method to simulate the interaction between ice sheet and a lighthouse, the simulation results indicate that the numerical method captures many of the qualitative observation as well as quantitatively derives comparable global ice loads to the lighthouse to those of the selected ice event. Zhang J et al. (2014) established the FEM models of ship and ice floe to simulate the ship-ice floe collision by LS-DYNA. They changed ice thickness, motion state and other parameters to research the structural dynamic responses of damage deformation of the ship. Wang JW et al. (2016) verified an ice material model by comparing the simulation result with experimental data, and they carried out the numerical simulation of an ice-breaker advancing in level ice to analyze the influences of the ship speed and level ice thickness on the icebreaking resistance.

In this paper, the numerical model of level ice is developed in the framework of finite elements by cohesive element model. For the verification of the numerical model, the simulations of uniaxial compression test and three-point bending test are conducted respectively to obtain the time history curve of load and displacement. During the simulation the size of ice specimens and loading methods are determined according to the strength test method in ITTC recommended procedures (ITTC Recommended Procedures and Guidelines 2014). The result shows the both strengths meet the requirement and the failure modes are similar to the model tests.

On this basis, the influence of water is taken in account to establish the ice resistance prediction method. Then an icebreaker sailing in level ice