Numerical Simulation of Ice Resistance based on FEM/SPH Coupling Method

Zhailiu Hao, Zhipeng Wang, Yukui Tian
China Ship Scientific Research Center, National Key Laboratory of Science and Technology on Hydrodynamics
Wuxi, Jiangsu, China

ABSTRACT

In recent research of ice resistance simulation, the coupling effect between ice and water is usually neglected. To consider the coupling effect of ship/ice/water, based on the finite element method and smoothed particle hydrodynamics method, the FEM/SPH coupling method is established. Then the ice mechanical properties and the ice resistance of a polar vessel are simulated. It is obtained that: (1) the numerical ice model is suitable for compression and bending strength calculation and has advantage on icebreaking simulation; (2) and the FEM/SPH coupling method is able to simulate the motion of broken ice in water and predict the ice resistance effectively.

KEY WORDS: Polar vessel; Ice resistance; FEM/SPH coupling method; Coupling effect; Broken ice motion.

INTRODUCTION

At present, with global warming and acceleration of sea ice melting, the opening rate of Arctic routes and the exploitation speed of polar resources are improved continually, leading to a great upsurge of polar vessel research at home and abroad. In such research area, the ice resistance is an important reference index for power analysis and hull form optimization, which has become a research hotspot. As for the ice resistance calculation, since the numerical simulation method can take into account the influence of sea ice failure mode and local hull details, more and more researchers are focus on the numerical simulation to improve calculation accuracy and application scope. Ren YZ et al. (2016) verified the feasibility of crushability foam model in ice material simulation, and simulated the icebreaking process. Tan X et al. (2013) proposed a numerical model of ice with six degree of freedom to capture the ship-ice contact process. Wang YH et al. (2013) obtained the continuous icebreaking process and the motion response of a direct navigation polar ship by using idealized icebreaking hypothesis. Gürtner A et al. (2009) simulated the interaction process between ice and lighthouse and obtained the distributed loads based on the bond finite element model. Wang J et al. (2009) used commercial FEM (finite element method) software to simulate icebreaking process of an icebreaker. In these researches, the interaction between hull and ice is mainly considered. But the coupling effect between ice and water is usually neglected, leading to the disadvantage of simulating the motion of broken ice in water and calculating the ice resistance caused by the sliding of broken ice on hull surface. To solve the above problem, in this paper the FEM/SPH coupling method is proposed to consider the coupling effect of ship/ice/water in ice resistance simulation. The numerical model of ice is constructed based on FEM, and the water is considered by SPH (smoothed particle hydrodynamics) method. On these basis, by using the contact algorithm of penalty functions to calculate the contact states and forces, the FEM/SPH coupling method is established. To implement this method, the software Abaqus is secondary-developed, and the ice elements and failure elements are generated by C++ programming. After that, the ice mechanical properties including uniaxial compression strength and three-point bending strength are simulated to verify the feasibility of the numerical ice model. Finally, for a polar vessel sailing in ice area, the icebreaking process, the motion of broken ice, and the ice resistance are simulated to verify the effectiveness of the FEM/SPH coupling method.

NUMERICAL MODEL

The numerical ice model is constructed based on FEM. On the basis of elastic-plastic model, the mechanical behavior of ice before plastic yield is described as:

$$\sigma = KD_{del} I + 2GD_e^'$$  \hspace{1cm} (1)

Where, $\sigma$ is stress, $K = E / 3(1-2\nu)$ is bulk modulus, $G = E / 3(1+2\nu)$ is shear modulus, $E$ is elastic modulus, $\nu$ is Poisson ratio, $D_{del}$ is swelling strain, $D_e^' = D_e - D_e I / 2$ is elastic strain deviator, and $D_e$ is elastic strain. The modified Drucker-Prager cap model is used in the yield criterion of plastic model.

In icebreaking process of polar vessel, cracks are occurred inside the ice due to stress concentration. With the propagation of cracks, the ice represents fracture failure. To simulate the ice cracks, the failure elements are constructed based on the cohesive element method. In this work, the ice elements with triangular prism type and failure elements with zero thickness are established, as shown in Fig. 1. In this figure, the failure elements divide the ice sheet into individual ice elements in both horizontal and vertical directions.