Analysis of ice resistance in ice-structure interaction based on the cohesive element method

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ABSTRACT

Cohesive Element Method (CEM) is based on fracture mechanics and Finite Element Method (FEM) and it can describe the generation of cracks to a certain extent through the failure of cohesive elements and has good reliability and accuracy. Based on the CEM, a cone-ice collision model is established, and the validity of the model is verified by comparing the simulation results with experimental data. This paper analyzes the effects of different simplification of the fluid on the ice resistance, and further analyzes the differences of ice resistance curves.

KEY WORDS: cohesive element method; numerical simulation; collision of structure and ice; level ice.

INTRODUCTION

In the context of climate warming, the Arctic ice is accelerating to melt, the topographic features of the Arctic are undergoing profound changes, and the difficulty of developing the Arctic has also declined. More and more ships have been used to develop the Arctic Channel. Following the development trend, more and more researchers have also devoted their efforts to the research of the safe navigation of polar ships.

Since the beginning of the 20th century, Runeberg (1900) might publish the first paper on ice load calculation methods for icebreakers. Scholars from various countries have studied the ice resistance of structures and the movement of structures under the influence of ice loads. The Finite Element Method (FEM) has been one of the main methods in this area, which has been developed fully and had a wide range of applications. With the development of computer technology, the scope of application of the FEM has been further expanded.

Although the FEM can effectively solve a part of the ship-ice collision problems under the assumption of continuous media (Li et al.,2018), it is not suitable for the calculation of discontinuous media and the simulation of crack generation and subsequent description of crack propagation. A new method is needed to describe the generation of cracks to a certain extent, especially it can be used to describe the failure process of ice and it must have good credibility and accuracy. The Cohesion Element Method (CEM) based on fracture mechanics is one of commonly methods in simulating crack problems.

The destruction and separation of ice is a macro manifestation of the formation of cracks in the ice. CEM connects bulk elements through cohesive elements whose thickness is much lower than the thickness of the bulk elements and simulates the formation of cracks between bulk elements through the failure of cohesive elements. When many cohesive elements fail and small cracks between the bulk elements evolve into obvious large cracks, the ice body is destructed and separated. The Dugdale-Barenblatt model (D-B model) was developed by Dugdale (1960) and Barenblatt (1962) to study the fracture problem of different materials. Based on the observed fracture phenomenon, the related theory was simplified into the Cohesive Zone Model (CZM). Needleman (1987) first referred to the crack region in the D-B model as CZM. Based on original CZM, many scholars improved the cohesive zone model and applied it to multiple fields. CEM is one of the numerical methods to perform the CZM. Because CEM can be regarded as a local damage model and overcomes the limitations of non-local damage models which is commonly used to simulate ice models (Sand,2008), it can solve fracture simulation problems based on FEM, and can predict and simulate the generation of individual fractures (Konuk,2009). In recent years, more and more scholars have applied CEM to sea ice simulation (Gürtner, 2009, Gürtner et al., 2010, Juha et al.,2013).

Because the failure of the cohesive element replaces the failure of the bulk element, the failing bulk element still participates in subsequent calculations. It can reasonably simulate the phenomenon of ice accumulation and secondary collision that CEM is used to simulate the collision of structures and ice. Although FEM is difficult to simulate ice breaking resistance and the submerged resistance at the same time, CEM can assure failed ice elements are still involved in subsequent calculations to simulate the submerged resistance. Wang (2018) used CEM to simulate the movement of ships in level ice with different heel angles and the simulated results were validated by comparing with the experimental results. Moreover, the level ice model built with CEM was...