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Cohesive Element Method to Level Ice-sloping Structure Interactions

Yihe Wang and Xin Yao
Ocean Academy, Zhejiang University (ZJU)
Hangzhou, Zhejiang, China

Fwu Chyi Teo and Jin Zhang
Department of Civil and Environmental Engineering, National University of Singapore (NUS)
Singapore

During the interactions between level ice and sloping offshore structures, crack initiations and propagations as well as the interactions between the resultant ice fragments occur. To simulate such complicated processes, the cohesive element method, which is capable of simulating dynamic fragmentation, becomes a potential numerical approach and has been applied to various kinds of offshore structures. One of the major challenges in applications of the cohesive element method is the mesh dependency or convergence issue for which remedies of random meshes and a random property field have been proposed in the context of concrete, ceramic, or glass fiber fracture problems. In this paper, random meshes based on Voronoi tessellations and a random ice property field following Weibull distributions were implemented into the numerical setup of the cohesive element method for level ice-sloping structure interactions to evaluate their performance in improving mesh convergence. Additionally, a new formulation based on added mass and hydrodynamic damping to capture the hydrodynamic effect of the fluid base was derived and utilized in the simulations. Based on a series of simulations, the time histories of the dynamic ice forces in the loading direction were compared with field data. It was found that an average Voronoi cell size close to the breaking length of the ice sheet yielded the best accuracy, since roughly all the cohesive interfaces near the structure failed in the simulations. This gives guidance in the determination of the average Voronoi cell size in the numerical setup according to empirical relationships between the breaking length and the ice thickness. Additionally, with the validated numerical model, the magnitude of the ice force in the transverse direction was found to be 30% of that in the loading direction, which serves as a preliminary method to determine the dynamic ice force in the transverse direction, facilitating the conceptual design of jacket structures with ice breaking cones.

INTRODUCTION

To reduce the ice force and mitigate the severe ice-induced vibrations of jacket structures with vertical legs under certain ice conditions, ice breaking cones are usually added to jacket structures at the waterline. However, ice-induced vibrations of jacket structures with ice breaking cones still exist because of the cyclic bending failures of the ice sheet and may result in crew discomfort and structure fatigue. Therefore, the prediction of dynamic ice forces on ice breaking cones in the loading and transverse directions is important to the design of jacket structures in arctic regions. In the process of ice–sloping structure interactions, radial and circumferential cracks form and propagate, resulting in ice fragments. And the ice fragments may accumulate in front of the structure, influencing the following bending failures in some cases. Such complicated processes are difficult to describe by analytical models; thus, predictions of dynamic ice forces on conical structures demand a numerical method capable of simulating both ice sheet fractures and subsequent fragment interactions.

The cohesive element method has been widely adopted to simulate the fracture of brittle or quasi-brittle materials such as concrete, ceramic, and glass fiber. Because of its capability of simulating both initiations and propagations of multiple cracks, as well as the ease of implementations in commercial finite element method (FEM) packages, the cohesive element method was also applied to problems of ice-structure interactions by different researchers. Konuk et al. (2009a, 2009b) and Konuk and Yu (2010) discussed the advantages of the cohesive element method over other numerical schemes for problems of ice-structure interactions and simulated ice crushing and bending failures. Gürtner (2009) applied the cohesive element method to study ice forces on shoulder ice barriers, ice protection piles, and the Norströmsgrund lighthouse. Hilding et al. (2011) simulated the ice crushing failure in front of the Norströmsgrund lighthouse by the cohesive element method combined with some homogenization method to capture subelement size cracks in a cost-efficient manner. Kuutti et al. (2013) simulated the crushing process of a thin slice in the middle of specimens utilizing a planar cohesive element model. Lu et al. (2014) developed a cohesive element model featuring a random field of ice fracture energies for ice bending failures. Liu and Wu (2012) studied the ice failures against truss legs of jack-up structures by the cohesive element method. In all these studies, the cohesive element method has been proven to be capable of explicitly simulating the branching and joining of multiple cracks and subsequent fragment interactions. However, a major challenge regarding the application of this method (i.e., the mesh dependency) has also been widely reported. A great number of investigations on the mesh dependency issue have been performed in the context of different applications, and remedies for the mesh dependency issue have thus been proposed.

In this paper, the cohesive element method is adopted to study the dynamic ice force during level ice-sloping structure interactions. The performance of random meshes based on Voronoi tessellations and a random ice property field following Weibull distributions in improving mesh convergence is evaluated in the context

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