Numerical Simulation of Sloping Structure-Level Ice Interaction Based on SPH-FEM Conversion Algorithm

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ABSTRACT

SPH-FEM conversion algorithm is proposed to simulate sloping structure and level ice interaction. This method combines the advantages of Finite Element Method (FEM) and Smoothed Particle Hydrodynamics (SPH), which provides a new idea for the research of ice engineering. In this paper, we used this method to simulate the interaction of sloping structure and level ice. Compared with the theoretical result by Croasdale 3D theory, this method predicted the icebreaking force correctly. Simultaneously, it accurately simulated the accumulation process of ice rubble as the failure finite elements were replaced by SPH particles. Thus, the SPH-FEM conversion algorithm is considered an effective way and will be used in the numerical simulations of ice structures or icebreakers.

KEY WORDS: Sloping structure; level ice; ice load; SPH-FEM conversion algorithm; rubble ice accumulation.

NOMENCLATURE

\[ D = \text{width of the structure} \]
\[ E = \text{elastic modulus of ice} \]
\[ f(r) = \text{physical variables} \]
\[ g = \text{gravitational acceleration} \]
\[ h = \text{ice thickness} \]
\[ h_f = \text{maximum ride-up height} \]
\[ h' = \text{smooth length} \]
\[ H_{(3D)} = \text{total horizontal force} \]
\[ H_{(2D)} = \text{bending failure load in 2D theory} \]
\[ H_{(3D)} = \text{bending failure load in 3D theory} \]
\[ l_c = \text{characteristic length} \]
\[ N_e = \text{number of elements associated with the particle} \]
\[ r_{0f} = \text{initial finite element size} \]
\[ W(r - r', h) = \text{smooth function} \]

\[ \rho_{0f} = \text{initial density} \]
\[ \rho_i = \text{ice density} \]
\[ \rho_j = \text{current density} \]
\[ \rho_w = \text{water density} \]
\[ \sigma_f = \text{bending strength} \]
\[ \nu = \text{Poisson's ratio} \]
\[ \Omega = \text{integration volume} \]
\[ < >= \text{kernel approximation} \]

INTRODUCTION

The operation of ships or offshore platforms in the Arctic is often in harsh environments, which mainly includes strong wind, high wave, sea ice, low temperature, icing and so on (Bridges et al., 2018; Dehghani-Sanij et al., 2017; Necci et al., 2019). Among them, the ice load on structures is the dominant environmental stress (Xu et al., 2015) and it can cause damage to offshore structures with serious consequences. For example, Vallinsgrunden lighthouse collapsed under several significant ice actions in 1979 (Bjerkás, 2007). Thus, some solutions were proposed to reduce or withstand ice load.

Sloping structures are widely found in marine structures to reduce ice loads, such as wind turbines and bridge piers (Barker et al., 2005; Brown et al., 2010) because these reduce bending failure of ice and are likely to be exposed to a severe dynamic ice load (Matskevitch, 2002). Depending on the conditions, the interaction between sloping structure and ice may produce several phenomena. For example, the breaking ice will move up the cone and then clear around the structure in the case of a narrow sloping structure. As for a wide one, rubble accumulation may form in front of the structure (Paavilainen, 2011).

Ice loads caused by the interaction between structures and ice need to be accurately simulated and calculated in the design and analysis of marine