Distinct Element Simulation of Ice-Structure Interactions

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ABSTRACT

Appropriate estimation of ice-structure interaction is of great importance in the design of offshore structures in ice-infested regions. The present paper deals with numerical simulations of three-dimensional ice-structure models done under the research project "Study on Ice Loads acting on Marine Structures", planned by Japan Ocean Industries Association (JOIA) and funded by the Ministry of International Trade and Industry.

In order to trace ice-failure process against a structure successively, distinct element methods (DEM) have been adapted, taking advantage of their tractability to non-continuous media over standard finite element methods, and PFC (Particle Flow Code)-3D by developed ITASCA, have been investigated.

In applying PFC-3D to floating ice-structure interaction modeling, model has been newly added to the original one, the buoyant-spring model to take the variation of buoyancy into consideration.

Then, some numerical results, including preliminary simulations of ice sheet on upward and downward breaking conical structure model, are presented.

In addition, modified PFC has been tested and examined its applicability to the simulation of failure mode of ice sheet caused by structures and the estimation of ice load against them, comparing with the results of ice tank test.

The conclusion of this study is that the present distinct element code has promise as powerful working tools for ice-structure interaction investigations such as prediction of ice sheet ride-up or push-down to and ice load against sloping structures.

KEY WORDS: Ice-structure interaction, Offshore structure, Distinct Element Method, Ice Load, PFC-3D

INTRODUCTION

It is generally accepted that for ships and marine structures operating in ice-infested waters, sloping structures are effective in reducing the ice loading because the ride-up ice on their sloped walls breaks into failure under the action of bending moment due to its own weight.

The ice loads acting on the sloping structures have so far been estimated mainly by continuum mechanics-based analysis and the principal result is the overall ice loads. Here, the analysis has been carried out quasi-statically by classifying the load into the one required to break the ice sheet and the one required to clear it, without taking account of the broken ice pieces. Therefore, such simulation programs have been desired that can deal with the successive failure of the ice sheet with irregular configurations and the resulting dynamic behavior of broken ice pieces, rubbles.

Hitherto, the authors have made efforts at developing such an alternative ice loading estimation method as to take the physical properties of ice and the movement of rubbles into consideration, taking advantage of the distinct element method (DEM) which makes it possible to quantitatively assess the dynamic behavior of non-continuous media. In the previous paper, they reported their DEM program and its applications, and, in addition, a sample simulation of ice-marine structure interaction by PFC developed by ITASCA.

The present paper is devoted to a detailed study on ice loading simulations on a sloping structure by a customized PFC-3D version by the authors and its applicability to this subject, based on their subsequent research.

SIMULATION TECHNIQUE AND CONCEPT

Applicability of DEM

DEM has been developed as a simulation method for predicting the behavior of non-continuous (granular) materials such as sand, soil and rocks. They are modeled as an assembly of granular rigid elements (particles), and normal and tangential springs and dashpots between the contact points of the elements. The motion of each element is calculated, based on the equations of motion of a rigid body under the action of external forces due to adjacent elements at the contact points.

Ice behaves quite differently from granular materials. In the first stage, ice floe shows the quasi-elastic behavior to a certain limit. With the onset of cracking in the ice floe, however, the behavior of the ice floe becomes far from continuous. Small floes flake away and break up with a kind of directionality. Separated ice blocks rub against and collide with the structure repeatedly.