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A Computer-Based Simulation of the Ice Fracture Near a Vertical Pile

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ABSTRACT

In this paper the pile interaction with the ice sheet rigidly frozen around it is considered. The ice sheet is moved against the structure in the horizontal plane by various external load factors. The problem is treated as a dynamic plane stress problem. The explicit finite-difference method is used in the FORTRAN program SHELF-M to investigate the ice-structure interaction. It is proved that the dimensionless ice strength parameters have great influence on the ice force value and on the interaction process.

NOMENCLATURE

b	: pile width
h	: ice thickness
p	: hydrostatic pressure in ice sheet
S_c	: compressive strength of ice
S_t	: tear strength of ice
t	: time
V_x, V_y	: ice particle velocities along x and y axes respectively
$\underline{V}$	: velocity vector
x,y	: Cartesian coordinates, connected with moving ice sheet
$\varepsilon_x, \varepsilon_y, \gamma_{xy}$	: strains in xy-plane
$\underline{\varepsilon}$	: strain tensor in ice sheet
$\sigma_x, \sigma_y, \tau_{xy}$	: stresses in xy-plane
$\underline{\tau}$	: stress tensor in ice sheet
σ_1, σ_3	: principal stresses in ice sheet (maximal and minimal)
ϕ	: internal friction angle for ice
$\underline{\underline{E}}$	: spherical tensor

INTRODUCTION

The ice loads are known to be the most dangerous factor for the offshore structures operating in an Arctic region. There are three ways to investigate them:

a. the observation of the ice-structure interaction in situ;

b. the simulation of the ice-structure interaction in the special ice basins;

c. the computer-based simulation of the ice-structure interaction.

Many experimental investigations have been performed to determine the forces which moving ice sheets exert on rigid structures. But the results of these experiments are not comparable as the values of maximal ice force in different experiments under the same conditions (aspect ratio b/h, pile cross section, etc.) have a very large deviation — 150% to 200%. This spread indicates some unknown factor, and this factor has essential influence on the ice load magnitude. We'd like to explain why this spread takes place and to determine those factors which have influence on the ice loads.

It is impossible to carry out such investigations by means either of the first or second way. To determine the degree of influence of all factors it is necessary to fulfill thousands of experiments in ice basins. So we have chosen the mathematical simulation as a method of investigation.

This paper deals with developing a simulation of deformation and fracture of the ice cover around the structure when an infinite ice floe moves in the horizontal plane against the structure with vertical supports and aspect ratio is high, i.e., the width of the structure is much larger than the ice thickness, so the plane stress condition can be used to investigate the stress distribution in the ice around the structure.

The most important problem in the simulation of the ice-structure interaction is modeling the ice behavior under the multiaxial stress conditions. The experimental investigations indicate that ice behavior depends greatly on salinity and temperature and on the ice floe's velocity. When the ice floe temperature is high and velocity is small, visco-plastic flaw of the ice near the structure takes place. This problem has been solved by Pulkkinen (1983, 1986, 1988), who used the finite elements method for this purpose.

When ice is cold and its velocity is high, elastic-brittle behavior takes place. The ice-structure interaction cycle consists of three main parts (Nadreau, 1987):

- quasi-static growth of the stresses in an ice field around the structure;
- very fast propagation of the fractured zone in an ice cover (the crack propagation velocity is about 3 km/s);
- relatively slow motion of broken ice in the structure.The ice load increases during the first part, falls during the second one and remains approximately constant during the third.

The quasi-static growth of the stresses in the first phase has been studied by various investigators using the visco-elastic models (Wang, 1983; Cammaert et al., 1986). The second and the third parts have never been simulated by means of the numerical experiments. But a similar problem has been studied by Hanagud et al. (1970) and Mansour et al. (1983), who have investigated the penetration and perforation of an ice cover by the metal cylinder within the scope of the dynamic axially symmetric problem of brittle material. The explicit finite difference scheme has been used by Hanagud (1970); the FEM has been used by Mansour (1983).

Our aim is to simulate the interaction cycle in toto. Some results of this work have been presented (Matskevitch et al., 1989, 1990, 1991).

ICE BEHAVIOR

Timco (1986) and Tomin et al. (1986) indicate three different modes of the ice global fracture near the structure:

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