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Indentation Contact and Penetration of Ice by a Semicircular Indentor

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ABSTRACT

Indentation contact and penetration of ice by a semicircular indentor are investigated computationally using the boundary element method (BEM). A series of BEM models is analyzed to show how the contact evolves from initial contact and penetration, up to the formation of macro cracks that result in ice splitting. Initial contact results in high contact pressure under the indentor, which causes local ice failure, thus marking the start of the penetration process. One effect of local ice failure is to cause the contact surface profile between the indentor and ice to become discontinuous; consequently, the contact pressure distribution upon further penetration is dominated by high pressures at the discontinuities. As the penetration process continues, existing discontinuities are destroyed by locally concentrated ice failure and new ones are formed. The result is a progressive migration of twin pressure peaks out to the contact limits. This process suggests a mechanism by which initial crack opening forces develop.

INTRODUCTION

When an indentor, or cutting tool, and ice come into contact, the ice is cut in a manner that resembles a machining process used to remove material by chipping. For brittle materials, such as ice, chipping is a discontinuous process characterized by fracturing that occurs near the tip of the indentor (Oxley, 1989). Such a process has been observed to occur when a marine screw propeller cuts a submerged piece of ice during ship navigation in ice-covered waters (Veitch, 1995). The contact and ice failure processes involved in the edge cutting of ice have been investigated in laboratory experiments by Veitch (1994). This investigation was continued using the boundary element method (BEM) by Veitch and Tuhkuri (1995).

This paper focuses on the contact between a semicircular indentor and an ice body during the early stages of contact and penetration. An attempt is made to show how the contact evolves during the penetration process, and how this process might lead to the formation and separation of ice chips. The problem is investigated using the BEM software BEASY. The boundary conditions used in the BEASY models of this problem correspond to those used in the laboratory experiments.

The basic problem is illustrated in Fig. 1. An ice block is frozen to a rigid support along two of its sides. The top and one side of the ice are free surfaces. A rigid semicircular indentor of radius R is pressed into the top surface of the ice. The tip of the indentor is located a distance h from the ice's vertical free surface. The contact limits are denoted by x_1 and x_2, subtended by the angles γ_1 and γ_2.

We begin by describing the basics of the BEM and how it is used in the present context of contact and crack problems. Then, a series of BEASY contact models is analyzed and the computational and experimental results are compared briefly.

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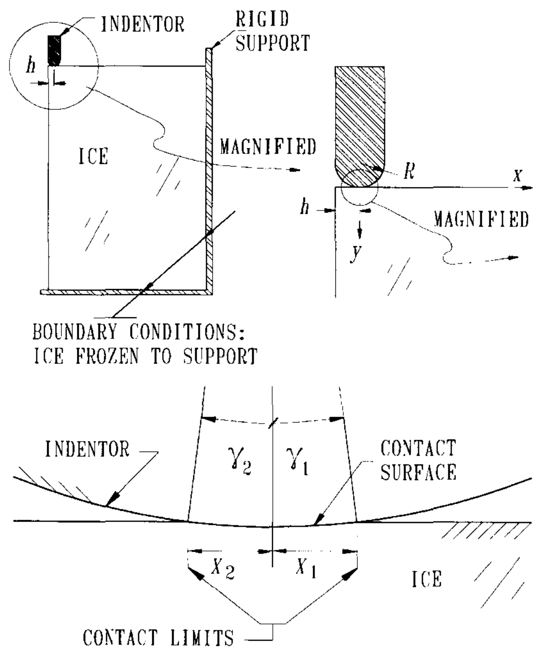

Fig. 1 Initial contact between semicircular indentor and ice

BOUNDARY ELEMENT METHOD APPLIED TO CONTACT AND CRACK PROBLEMS

The central feature in all contact mechanics problems is that the contact area and the contact mode (stick or slip) are not generally known beforehand but are solved during the analysis. Therefore, the problem must be solved iteratively. In addition, the analysis must be incremental. In some special cases where all the stress components within the system increase or decrease in a uniform manner, the incremental formulation and a total formulation will give equal results, but in general the two approaches are not expected to give the same result. A contact problem is nonlinear not only because of the friction phenomenon but also because the boundary conditions may change as the load increases.

The contact variables are the unknown boundary values at the contact area, that is, displacements and tractions of the pairs of nodes that are on the opposite sides of the contact interface. Fig. 2