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Contact Force and Damage Evolution in a Moving Uniaxial Ice Bar

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ABSTRACT

In order to investigate ice forces on offshore structures, the impact of a semi-infinite moving ice bar is considered. Based on typical observations of ice-structure impact, a continuum damage mechanics approach for ice property descriptions is adopted to describe the microcrack initiation. The method of characteristics is applied to solve governing equations of the wave propagation problem with the evolution of continuum damage. The numerical results, using representative published ice properties, show some interesting aspects of the initial stages of the ice-structure interaction process. The results serve as an initial attempt to put ice load predictions, including damage evolution, on a solid theoretical basis.

INTRODUCTION

Ice forces acting on marine structures in the Arctic region have been of crucial interest to designers and researchers. Because of the various failure mechanisms of the ice, e.g., spalling, flexural cracking, splitting, and plastic flow, it is very difficult to simulate the breaking mechanism by a simple model of the ice. The actual forces generated when ice features impinge against a structure involve a complex interaction of various failure modes as penetration continues (Timco, 1989).

Among various scenarios of indentation processes, we consider the impact of an ice floe against a structure that involves the following stages (Timco and Jordaan, 1987) :

i) Initial impact causes a rapid rise of the interaction force.

ii) Ice sheet deforms and damage evolves to a limited extent.

iii) Progressive failure by fracture, followed by clearing the debris formed during the contact, makes the force fall to zero.

A simplified theoretical model of the above-mentioned ice-structure impact scenario can be made possible when the continuum damage mechanics approach is used for the constitutive modeling of ice. This allows for a description of microcrack damage in the medium. However, the clearing process is yet revealed theoretically in this paper. Sanderson described the clearing process and quantified the clearing force required to remove the debris (Sanderson, 1988). Jordaan and McKenna (1989) and Choi (1989) reviewed the historical approach of the continuum damage mechanics and its application to the ice mechanics.

A typical example of an ice-structure interaction is shown in Fig. 1, where the structure is considered as a rigid wall. A semi-infinite ice strip is moving toward the structure. At $t = 0$, the ice hits the structure. Then, the velocity boundary condition $v = 0$ can be applied at the ice boundary. As time passes, stresses are generated in the ice, and the velocity changes within the ice. The stress, strain and damage propagate with the speed of c_d , which is the damaged wave speed and will be discussed later. At a certain time t_{cr} , the continuum microcrack damage evolves in the bar. After the damage reaches a certain critical value, the phenomena to clear the debris may occur in the ice bar. Clearing phenomena are beyond the scope of our analysis.

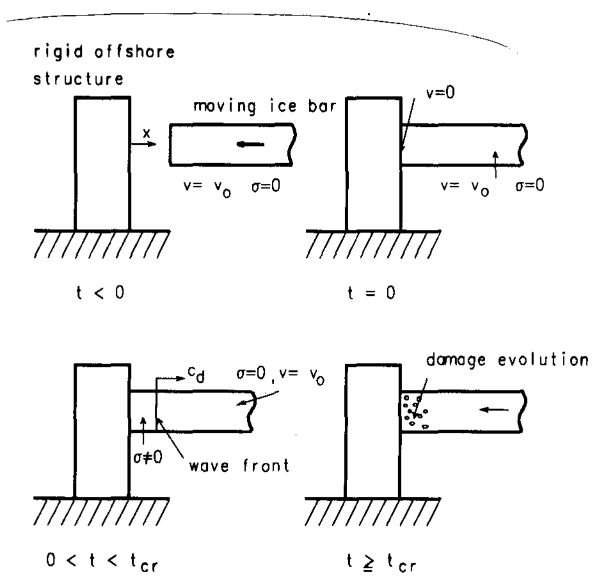

Fig. 1 Impact of a moving ice bar

In the following analysis, we further simplify this scenario by assuming a uniaxial state of stress within ice. The ice sheet is therefore considered as a semi-infinite ice bar. This is a very important assumption, which enables us to establish procedures for calculating the uniaxial stress developed during the initial stages of the impact process. The numerical results of the analysis must, however, be interpreted in light of this simplification. It should be noted that the three-dimensional nature of the actual stress state would affect the damage evolution.

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