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Damage Evolution During Impact of an Ice Bar with Lateral Confinement

Dale G. Karr and Xin Sun
The University of Michigan, Ann Arbor, Michigan, USA

ABSTRACT

A study is presented of the theoretical response of ice subjected to constant velocity impact. The ice medium is idealized as a bar of fine grained polycrystalline ice that is confined in one direction perpendicular to the impact axis. A three-dimensional continuum damage model is used to define the constitutive response of the ice. The physical model consists of a finite length bar, and the impact problem is formulated by prescribing the boundary conditions of zero velocity at one end and a constant velocity at the other end. A finite difference scheme is employed to solve the governing system of differential equations. Comparisons are made for conditions of uniaxial stress, biaxial stress and plane strain. The contact stresses and the evolution of damage are found to be highly dependent on the degree of lateral confinement. It is also found that higher velocities lead to more highly concentrated damage zones.

INTRODUCTION

Ice loadings pose serious threat to structures and floating vessels in ice-covered waters. Uncertainties in ice load predictions can result in unnecessary construction delays, higher costs, and increased risks. Three aspects of concern are the global ice forces exerted on the entire structure, the local ice loads that are described in terms of distributed pressures and contact areas, and the dynamic interaction between the ice and structures. The existing technology for predicting local and global ice forces is far from satisfactory, although much progress is being made (Jordaan et al., 1991). The difficulties in establishing appropriate ice forces for structural design are due to the complexities and uncertainties in describing: i) the mechanical behavior of ice; ii) the characteristics of the ice features that may be encountered; and iii) the nonlinear coupling between the ice and the interacting structures. Ice is generally found at temperatures close to the melting point and thus the mechanical properties are highly dependent upon loading rate. At one extreme, particularly when deformed at high strain rates, ice may deform elastically and fracture in a brittle manner. Inelastic deformations are predominant at lower strain rates, and response may be described as viscous or plastic. Considerable microcracking occurs in addition to viscous and elastic deformation at intermediate strain rates, which generally occur during ice-structure interaction. Continuum damage mechanics models have been successful in bridging the gap between the two extreme cases. Several constitutive models have been proposed, which are based on continuum damage mechanics; among them are Karr and Choi (1989), McKenna et al. (1990), Sjölind (1987) and Wu and Shyam Sunder (1991).

Interaction forces are also dependent upon the geometry of the impacting ice feature. Ice features may fail (and thus limit the interaction force) in different modes: local crushing, flaking, cracking, and buckling (Blanchet et al., 1989). The mode of failure is influenced by the rate of penetration, the thickness and type of ice and the indentor geometry. These failure modes may interact, resulting in progressive failure of the ice. Imperfections in the ice feature such as existing flaws, thickness variations and irregularities in the contact area can also affect the failure of the ice. Local deformations at the ice-structure interface can also influence global failure due to redistribution of contact forces.

There have also been studies of the nonlinear dynamics involved with the vibration of a structure or ship as it impacts with an ice field. Laboratory studies (e.g. Sodhi, 1991; Stern et al., 1989) and field studies (Jefferies and Wright, 1988) demonstrate the influence of velocity and geometry on the dynamic interaction. In the analytical studies, the ice medium is highly idealized and the strength and breaking patterns of the ice are often prescribed rather than calculated. See for example Matlock, Dawkins and Panak (1969, 1971), Tsuchiya et al. (1985), Daoud and Lee (1986) and Comfort et al. (1992).

It has recently been found that the global response of such a highly simplified ice model as that of Matlock et al. is very complex, with multiple periodic solutions for the motion of the structure being possible for a single system (Karr et al., 1993, and Troesch et al., 1992). The systematic study of the simple Matlock model has demonstrated that very complicated dynamics can result due to the effects of nonlinear, intermittent forcing of the structure. Even when the ice properties and geometry are known or at least assumed, a wide range of dynamic response is possible. The complexities of the dynamics of ice-structure interaction are therefore not necessarily caused by the complexity of the ice deformation, interface geometry or ice-breaking mechanisms. Also, analytic results simulating the interaction process may represent only a very limited description of the response of the system. Slight changes in tolerances or initial conditions may have considerable influence on predicted response. Questions remain therefore as to the appropriate level of modeling of the ice media for practical applications of such dynamic analyses.

This paper focuses on establishing methods for analyzing the local crushing phenomenon near the ice-structure interface using continuum damage modeling. It is felt that this is essential for establishing local pressures for structural design. It is also considered an important step for predicting global ice forces because of the influence of local crushing on the eventual large-scale failure of the ice. In this study, the indentation velocities are prescribed as constant during the indentation process. A methodology is established for solving ice-impact boundary value problems with emphasis on examining the influence of lateral confinement. Finite difference modeling is employed and offers benchmark solutions for the application of multipurpose finite element codes. These studies serve to establish a basis for further developments to include more general interaction geometries and global descrip-

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