Symposium of Advances in Contact Mechanics: a tribute to Prof. J.J. Kalker
22 - 24 October 2008, Delft, The Netherlands

Fragmentation of Ice During Contact

A.P.S. Selvadurai
McGill University, Montreal, QC, Canada

Keywords: ice mechanics, fragmentation, discrete elements, viscoplasticity,

1 INTRODUCTION

The term *brittle* is intended to signify a mechanical state that a material can achieve through the control of a number of factors including the stress state, the temperature, the loading rate and through a choice of scale. A characteristic feature of brittle behaviour is the development of extensive micromechanical damage and its localization, with fragmentation as the end result. Ice in its unconfined state is a material that can fragment with the application of stresses at various rates. The brittle fragmentation of ice is of significant interest to engineering activities in the High Arctic, particularly with reference to energy resources exploration, marine navigation and geophysical research in the earth sciences. This paper examines the problem of the interaction of an isolated floating ice floe with a stationary structure. For the purposes of the modelling, it is assumed that the ice floe has a constant thickness and all deformations take place in the plane of the interaction. The analysis of the interaction can also be performed by taking into account three-dimensional contact at the interaction zone. The study of the interaction between the ice floe and the stationary object can be approached by considering a variety of models; the most elementary of these is the representation of the ice floe as a rigid object, which converts the problem to the straightforward interaction between rigid bodies, where the solution is governed by equations of classical dynamics. A modification to this approach involves the incorporation of elasticity of the impacting ice sheet and the resulting analysis is an initial boundary value problem in elasto-dynamics, where in-plane dynamics can be taken into account. A further advancement to this model is to include either rate sensitivity or viscoelasticity in the deformability characteristics of the ice floe. These models have been used in the study of the interaction of ice sheets and both stationary and moving objects. What is absent in many of these modelling approaches is provision for processes such as rate sensitive failure and the development of fragmentation during the interaction process. The models that could be used in such advances must of necessity be kept to a manageable level since the parameters that are used to describe the interaction and fragmentation process are difficult to determine in a practical context.

2 COMPUTATIONAL MODELLING

The dynamic interaction between an ice floe and a stationary structure is examined by considering the following attributes of the computational modelling of fragmentation: (i) isotropic elastic behaviour of the ice floe in its initial state, (ii) viscoplastic failure of the ice governed by a Mohr-Coulomb-type failure criterion and the development of viscoplastic strain rates according to an associated flow rule (Davis and Selvadurai [1]), a fluidity parameter and a flow function of the Perzyna-type [2], (iii) development of fragmentation of an element initiated by either a maximum direct tensile stress or direct compression and based on a Mohr-Coulomb rule (iv) the limitation of continued fragmentation of the ice fragments themselves by assigning a size-dependent tensile strength, (v) the frictional interaction between individual fragments based on a Coulomb criterion with in-plane stiffnesses derived from a Hertzian plane contact model for discs and (vi) the computational modelling of the interaction process in a complete dynamic fashion, with provisions for examining the stability of the time-integration scheme for both viscoplastic and dynamic phenomena [3,4].

We examine the problem of the interaction of a circular ice floe with a stationary pier with a circular interacting edge. The plan dimension of the ice floe approximately corresponds to a circular region of diameter 10 m. The thickness of the ice floe is taken as 1 m. Typical numerical values are assigned to the parameters that are required to model the interaction process. The ice floe obliquely impacts the stationary pier at 0.2 m/sec. The results shown in Figure 1 illustrate the mode of fragmentation of the ice floe and the time history of the average contact stresses that are generated at the contact zone between the ice floe and the stationary pier. The maximum value of the contact stress is generated immediately upon impact and, as fragmentation commences, the contact stresses are substantially reduced.

3 CONCLUDING REMARKS

Fragmentation can be realized in elastic brittle materials that attain failure under little or no confinement. The paper presents a computational approach that can be used to examine such fragmentation processes by taking into consideration elasto-viscoplasticity of the ice prior to fragmentation and the interaction of fragments as material regions with similar properties and inter-fragment interactive phenomena with a frictional response. The modelling illustrates traits of the responses of individual ice floe fragmentation observed in the field.

4 REFERENCES

[1] R.O. Davis and A.P.S. Selvadurai, *Plasticity and Geomechanics*, Cambridge University Press, Cambridge (2005).

[2] P. Perzyna, Fundamental Problems in Viscoplasticity, *Advances in Applied Mechanics*, Academic Press, New York, (1966) 243-377.

[3] O.C. Zienkiewicz and I.C. Cormeau, Viscoplasticity, plasticity and creep in elastic solids-a unified numerical solution approach, *Int.J. Num. Meth. Engng*.Vol.8 (1974) pp. 821-845.

[4] D.R.J. Owen and E. Hinton, *Finite Elements in Plasticity*: *Theory and Practice*, Pineridge Press, Swansea (1980)

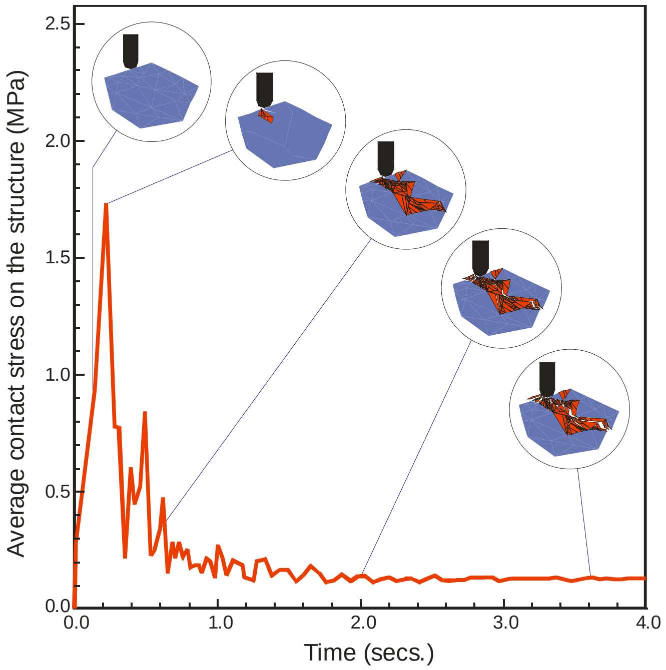

Figure 1: Fragmentation of the impacting ice floe