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Finite element analysis of surface cracks in the Wilkins Ice Shelf using fracture mechanics

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Ice shelves, located between the warming atmosphere and the ocean, are sensitive elements of the climate system. The Wilkins Ice Shelf is situated in the south-western part of the Antarctic Peninsula, a well known hot spot of global warming. Recent break-up events exemplified the potential of disintegration of the ice shelf. A multi interdisciplinary project consisting of remote sensing, modeling of the ice dynamics and fracture mechanics intends to improve the understanding of the impacts of temperature increase on ice shelf stability. As a part of this project the aim of this presentation is to demonstrate the fracture mechanical approach using finite elements and configurational forces.

For fracture mechanical purposes the material behavior of ice is treated as a brittle solid, and linear fracture mechanics is used. Crucial to all methods in linear fracture mechanics is the evaluation of the stress intensity factor K which is a measure for the load concentration at the crack tip and which depends on the geometry of the body and on the applied loading. The computed value of K can be compared to the critical stress intensity factor K_c, a material property obtained from experimental examinations, to judge whether a crack will propagate. One very effective procedure to obtain the stress intensity factor takes advantage of configurational forces, which can be easily obtained in the finite element analysis.

An initial investigation is based on a 2-dimensional analysis of a single crack with a mode-I load type using a static plane strain model in the finite element analysis software COMSOL and additional routines to compute and evaluate the configurational forces. Analytical solutions of simple geometry and load cases are called on in comparison. The application to the Wilkins Ice Shelf follows by using material parameters, geometries and loading situations, which are obtained from literature values, remote sensing data analysis and modeling of the ice dynamics, respectively.

The examined 2-dimensional geometry describes a vertical cut in a horizontally endless ice shelf creating a rectangular plate fragment. The crack, located in the middle of the plate is opened at the ice/atmosphere transition. The crack opening is small compared to the length of the plate. The plate is loaded on the lateral boundaries through a uniform tensile load resulting from the dynamical analysis and the hydrostatic pressure of the ice mass. The finite element analysis aims to examine the influence of the depth of the crack in connection with the inhomogeneous material properties of the different ice layers, which can be found in the ice shelf. Furthermore the influence of water inside the crevasse, resulting in an additional loading of the crack faces, is discussed. The results of these parameter studies are then used to obtain a measure for the crack induced compliance reduction of the ice to be used as an input for the modeling of the ice dynamics.