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The Cryosphere Discussions

Interactive comment on "Evaluation of the criticality of cracks in ice shelves using finite element simulations" *by* C. Plate et al.

Anonymous Referee #1

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This manuscript presents an analysis of the instability of crevasses in ice shelves from finite-element calculations. This is an old problem, tackled by several authors in the past, generally from analytical calculations. However, the finite-element method used in this study can be potentially a way to explore more complex situations, such as complex density profiles or situations subjected to brine infiltration. In that sense, the approach proposed here is potentially interesting, the subject is timely and certainly relevant for The Cryosphere. However, in my opinion, several important clarifications and probably complements are needed before publication.

1) To estimate stress intensity factors (K), the authors calculate first stress energy release rates (Gy) using the method of "configurational forces". A detailed comparison with other classical FE methods to estimate K is needed here: - Is this "configurational

forces" method similar to, or (or not) inspired from the perturbation method (Parks, Int J Frac 1974) ? If not, what is its advantage ? - the calculations are done here with elements with quadratic shape functions. For fracture mechanics problems, special elements dealing with 1/(rˆ1/2) singularities can be used and are more adapted to correctly estimate K. Did the authors try to use these elements ?

2) Sections 2.4 to 2.6: In their simulations, the authors prescribe vertically constant displacements, as they argue that at large distance from the grounding line, horizontal velocities and displacements are depth-independent. Although some references would be useful here, this might appear as a reasonable approximation. However, to apply displacements instead of stresses can lead to some tricky problems. In section 2.4, the authors explain that the boundary displacement Delta_u is linked to the normal stress at the surface (no effect of the overburden pressure) through a linear elastic rheology. But, just below, they indicate that this stress is calculated using a viscous rheology (Glen's law). There is therefore a contradiction here. This contradiction is also present in Rist et al. (JGR 2002), but this was more justified in this case based on analytical calculations. In the real world, both rheologies are coupled, and play a different role depending on time scales. Finite-element calculations could be a way to model the full problem. In this case, velocities instead of displacements should be used as BCs. In the simulations of this manuscript, displacement BCs are applied (and do not evolve through time). Imagine an elasto-viscous body on which you apply - instantaneously – some displacement Delta_u. The obtained stress field at t=0 would be the one calculated by the authors, but this stress field will relax as the ice creeps. As the instantaneous application of a fixed displacement is an unrealistic scenario in case of ice shelves, this raises problems for the interpretation of the presented results in terms of crevasse instability. A more realistic scenario would be to apply velocities instead of displacements: in this case, the instability will depend strongly on the rate of loading, i.e. on the possibility to relax by creep the increasing elastic stresses. In addition, for prescribed velocity BCs, the presence of crevasses will modify the obtained surface stresses. These problems explain why previous analytical approaches (e.g. Smith,

J.Glac, 1976; Van der Veen, Cold Reg Sci Tech, 1988, ...) considered stress BCs, even if they introduce other simplifications. In conclusion, I do not see a real breakthrough here compared to previous analytical works, whereas the FE approach could potentially allow such progress.

3) p471, L9: "an elastically compressible solid": this precision might be useful to avoid confusion with incompressible (e.g. plastic) flow.

4) p474, L7: "the identity tensor I" (and not 1)

5) section 2.3: the so-called crack driving force is actually an energy release rate (see e.g. eq. (18))

6) section 2.5: what is the evolution of the mesh size as approaching the crack tip ? Are the results dependent on this "rate" of refinement ?

7) equation (20): B (creep constant ?) and rho_sw (density of sea water ?) should be defined.

8) p479, L5-6: "The stress intensity...(Bueckner 1970)": Not clear. Does this mean that K is not estimated from eq. 18 ?

9) p479, L8: "which ranges between (1-4) Pa.m^1/2" ???? Fracture toughness of ice is around 100-150 kPa (see e.g. Schulson and Duval, 2009).

10) p480, L4-6: "This approach requires...". I do not understand why, as stresses (and not displacements) are not prescribed in this case.

11) p480, L11: For a polycrystalline ice with isotropic fabrics, the Poisson ratio is very close to 1/3, and does not vary significantly with e.g. temperature. Variation in the range 0.2-0.4 are only obtained for strongly anisotropic fabrics (see e.g. Schulson and Duval, 2009). In this case, nu is axis-dependant, and not isotropic, with possible fluctuations with depth (as fabrics changes). Therefore, I do not really understand this discussion about the Poisson's ratio (section 3.2). Moreover, this dependence of the

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results on nu comes from the displacement BCs (and not stresses) approximation.

12) p482, L15-16: KI<KIc is a poor crack arrest criterion. In general, as dynamic effects have to be taken into account during unstable propagation (KI>KIc), the arrest is observed for K«KIc: see e.g. the classical (Ravi-Chandar, Int. J. Fracture, 1984). KI>KIc is a good crack initiation criterion for unstable crack growth. It tells nothing about how a crack (a crevasse here) can reach the critical depth (in this manuscript, the creep strain-rate, and so the surface tensile stress, is considered to be constant through time). To describe this, sub-critical crack growth has to be considered. In the context of crevasses, this point has been tackled by (Weiss, J. Glac., 2004).

13) p484, L21-22: The exponential dependency of E is probably related to a strong dependency of E on porosity in firn (see e.g. Schulson and Duval, 2009). This strong, non-linear dependency of E on r calls for a coupled analysis of the effects of both parameters (i.e. to unite sections 3.3 and 3.4)

14) the legends of fig. 1(c) are unreadable

Interactive comment on The Cryosphere Discuss., 6, 469, 2012.