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Comment on tc-2022-140

Anonymous Referee #1

Referee comment on "A closed-form model for layered snow slabs" by Philipp Weißgraeber and Philipp L. Rosendahl, The Cryosphere Discuss., https://doi.org/10.5194/tc-2022-140-RC1, 2022

Comments to tc-2022-140

This manuscript with the title of “A closed-form model for layered snow slabs” presents a closed-form analytical model for the purpose of investigating and predicting the physical processes that lead to the formation of dry-snow slab avalanches. The reviewer found this manuscript has significant issues regarding fundamental methodology, the weak layer failure mechanisms, validation and conclusions. Therefore, the reviewer do not recommend publishing this manuscript considering the following points.

- Section 2 in the manuscript presents the proposed model using continuous laminated beam or plate theory to establish a kinematic model of snowpack. This model can only analyse continuous deformation instead of fracture phenomena of snowpack especially in the weak layer. It is well known that the weak layer failure is a mixed mode damage and fracture propagation, which should be a fundamental study in assessing snow avalanches. The reviewer would suggest authors reconsidering the methodology in investigating snowpack fracture using fracture mechanics approach together with laminated plate theory.
- Figure 1 show a schematic model of layered snowpack, in which a weak layer is modeled as an elastic foundation using two springs with stiffness K_n and K_t. But this manuscript did present how normal and shear stiffness are coupled in the weak layer. It was mentioned bending and extension coupled in snowpack body as a layered beam. But the failure is in the weak layer, studying coupled effects in the weak layer is much more important than the snow slab above the weak layer.
- Figure 4 shows some different snowpack cases with initial cracks. Fig. 4b is an upslope PST. This is a major case regarding snowpack propagation saw test (PST), some researchers have done experimental work and modelling simulation. The following published papers are for authors’ reference:

- Gaume, T. Gast, J. Teran, A. van Herwijnen & C. Jiang, Dynamic anticrack

propagation in snow, Nat. Commun. DOI: 10.1038/s41467-018-05181-w.

- Gaume, A. van Herwijnen, G. Chambon, N. Wever, J. Schweizer, Snow fracture in relation to slab avalanche release: critical state for the onset of crack propagation, The Cryosphere 11 (2017) 217–228, https://doi.org/10.5194/tc-11-217-2017.

- Jiye Chen, Blair Fyffe, Dawei Han and Shangtong Yang, Predicting mixed mode damage propagation in snowpack using the extended cohesive damage element method, Theoretical and Applied Fracture Mechanics 122 (2022) 103567, https://doi.org/10.1016/j.tafmec.2022.103567.

Reference c summaries the weak layer’s fracture mechanisms in the upslope PST case. It is well accepted to recognise a mixed mode damage and fracture in the weak layer under compression and bending. This can also be seen from Fig. 4b, the left part of segment 2 is under compression and shear and the right part under tension and shear. The left part is subjected to both compression and bending in the same way in compression. The bending caused tension and compression have opposite effects on the right part. The left part of segment 2 would fail by compressive crushing and shearing. Once the weak layer fails by the mixed failure mode with crushing and shearing, the snow slab moves down due to gravity. Reference c proposed a new mixed mode damage criteria and successfully assessed the weak layer’s failure initiation and propagation. But this manuscript concluded that the upslope PST is a mode I crack (opening). This is questionable. This manuscript has not yet considered the micro damage phenomenon in the weak layer because of the continuous mechanics model used, which cannot reflect the reality of failure in the weak layer. Snow is a porous material with micro crystal construction, which can be easily crushed by compression.

- Equation 19 and Figure 16 present a total energy release rate in the weak layer: $G = G_1 + G_2$. But this manuscript has not used the G for assessing crack propagation. Theoretically, total G is not total fracture energy criterion G_c in the mixed mode case, it contains contributions from G_{1c} and G_{2c} in a coupled model. This important point was missed by this manuscript.
- On page 9, the last sentence: " Energy release rates obtained using weak-interface kinematics cannot capture very short cracks …. ". This is a case from the kinematic model. However, if energy release rate obtained by fracture mechanics in weak layer, it can certainly capture any crack length. This has been done in standard fracture benchmarks of laminated composites in literatures.
- Section 3 in this manuscript presents validation. It compared the outcomes from the proposed analytical model with FEM based continuous deformation analysis regarding deformation and stresses. There is no usage of test results in validation. This is also questionable. Firstly, the modelling results from FEM based continuous analysis are not reliable when the FEM mesh with cracks, or without validation by test work, the FEM results would not be accepted to validate other new models regarding fracture issues.
- On page 12, the last paragraph, " Experimental validations are challenging since direct measurements of stresses are not possible and displacement measurements require considerable experimental effort ". This is truth. However, above references a and b reported critical initial crack length in PST experimental work, which causes crack propagation and sliding of snow slab above weak layer, and the critical initial crack length related bending moment can be used for validation if the critical load can be provided by the analytical model in this manuscript. But this manuscript failed at the validation in this way. Abovementioned reference c has completed a similar validation.
- In example section, manuscript presents a lot of information about stress and deformation distributions in snow slab in different cases. The reviewer thinks this information is less important in assessing snowpack fracture. The outcomes from this proposed model are not only difficult for validation and also in application for assessing snowpack fracture initiation and propagation. As a closed-form solution, it is expected to provide precise failure response which shows a load-deformation curve. Thus, it can clearly present elastic stage, damage point, damage accumulation and final crack point.
- This manuscript mentioned a basic concept of a failure mode in weak layer: mode I (collapse) or anticrack. Although this terminology was used by some researchers in their early work. The reviewer thinks that this terminology is not in the line of the basic concept of fracture mechanics about mode I: opening crack. The wording of collapse or anticrack would not be a right description of the failure mode in opposite way of mode I. Abovementioned reference c properly suggested a terminology of crushing damage by compression, and proposed a mixed mode damage criteria with crushing damage and shearing crack (mode II) to assess the failure in weak layer under mixed loading.
- A closed-from should clearly present the failed load and residual strength when crack propagates through the failure response or load-deformation curve. The reviewer thinks that this manuscript has not reach the purpose of investigating and predicting the physical processes that lead to the formation of dry-snow slab avalanches.