Review of Damsgaard, A., Egholm, D.L., Piotrowski, J.A., Tulaczyk, S. Larsen, N.K., and Brædstrup, C.F., **A new methodology to simulate subglacial deformation of water saturated granular material**: Submitted to *The Cryosphere*

General

The authors describe an elegant numerical model of a deforming granular subglacial material. (I am not qualified to evaluate the numerical model.) It is satisfying that the results are consistent with laboratory experiments and well-understood physics. However, the conclusions are, I think, already pretty well-known, and in that respect the paper does not seem to provide much insight into subglacial processes. Perhaps the paper should be written as a model description and validation paper, as the title actually suggests. This would require minimal change. It would simply involve statements along the lines of, "See, the model does what we know it should do, so despite its short-comings (large grain size, no clay,…) it is reproducing nature." Alternatively, perhaps the authors can make some predictions using the model that are not already understood, but are supported by field evidence.

Under the best conditions modelled, deformation extended only two to three decimeters into the bed, yet it is known that deformation extends to greater depths in nature. Can the authors explain what is necessary to get deformation at greater depths? I don't think this is really understood, and it would be a nice contribution.

The "Results" section contains a lot of unsubstantiated statements and interpretation. Interpretation should be clearly distinguished from the "facts" that are evident in graphical (or numerical) results.

The changes in peak stress and mean fluid pressure from one experiment to another are very small and if they were based on physical experiments, most readers would consider them to be within the limits of uncertainty of the experiments. What happens if you repeat an experiment from the beginning, numerically dumping a new assemblage of particles (with the same particle size distribution) into your "dry, tall volume"? Are the results in Figures 4 and 7 reproducible to the degree that you can argue that the differences among panels of those figures are real?

Specific comments

(p. 3, Line 23) "…is, over time, carried…" Add commas

(p. 5, Line 5) "In this study, we explore the…" The study is not a person and thus can't, itself, <u>do</u> anything.

(p. 6, Lines 5-14 and elsewhere later) Please define all symbols used in your equations. Here I don't see definitions of g, t, r, and k. Two of these will be fairly obvious to most readers, but don't leave the reader guessing. In equation (6), V_g is not defined and in equation (8) $\boldsymbol{v}$ is not defined.

(p. 6, Line 17) How is linear elasticity involved? I don't see any elastic constants in any of the equations.

(p. 7, Line 6) "…2012) <u>because</u> it allows convenient…" "Since" involves time.

(p. 7, Line 14-15) Symbol k now appears to have a different meaning than in equation (3).

(p. 9, Line 13) "…and is of…" Add "is"

(p. 9, Line 16) "…constraints…" Second 't' is missing.

(p. 9, Line 17-18) If I understand this, you mean, "…we are unable to give fine grain sizes ~~with~~ realistic elastic properties ~~within a reasonable time frame~~."

(p. 13, Lines 9-17) (*i*) You write this as if it were a physical experiment in a soil mechanics laboratory, not a numerical experiment on a computer.

(*ii*) Also, perhaps here, you should say something about the physical size of the modelled domain (0.4 m according to Figure 5)

(p. 14, Line 9) "…viscosity, the…" Add comma

(p. 14, Lines 21, 23) Neither Figure 4 nor Figure 5 show rates of dilation. The middle diagrams in Figure 4 show that dilation increases roughly linearly with shear strain, but to get a rate out of that one has to – what(?) – also divide by the shear velocity?

(Figure 4) You seem to be equating "peak strength" in the caption with "shear friction" on the y-axes in the top row. Why use different terminology?

(Figure 5) (*i*) Lettering is too small on axes.

(*ii*) "…fluid pressures (y axis)…" If I am interpreting the graphs correctly, the fluid pressures are not shown on the y-axis, they are shown by the color scale. The y-axis appears to me to be the vertical height above the bed.

(p. 14, Lines 25-27) I read the peak values in Figure 4 at 0.65 and 0.61 respectively.

(p. 15, Lines 7-8) What is the "pure granular strength"?

(Figure 6) (*i*) Why are there two points at a shear velocity of 10^2?

(*ii*) The "constant frictional strength" at low shear velocities is not shown in the graph. In fact, if I draw a curve through the points shown, peak shear friction continues to decrease at shear velocities less than 10^1 m a^{-1}.

(p. 15, Line 12) In this line you use shear stress but elsewhere you use shear friction. What's the difference? If they are fundamentally interchangeable, I suggest using shear stress (or better yet, "shear traction") throughout (including in figures).

(p. 15, Line 17) "…low-permeabil<u>ity</u>…"

(p. 15, Line 18) "…largest…" The difference is pretty subtle.

(p. 15, Line 20) In both Figures 4 and 7, the deviation of fluid pressure from 0 is very subtle. You need to find a way to make it more obvious so readers can easily see what you describe in the text. You also need to find a way to convince the reader that the very small changes from one experiment to another are physically meaningful. Certainly, if you were reporting a physical experiment, most readers would consider the differences to be within limits of experimental error.

(p. 15, Line 25) "…~~more~~ shallow<u>er</u> deformation…"

(Figure 9) (*i*) In two places in the caption you mention shearing velocities. These are not shown in the figure and should not be mentioned.

(*ii*) "…porous flow…" Do you mean Darcian flow?

(p. 16, Line 1) "values (<u>Fig. 9 right</u>, red)…."

(p. 16, Line 2) "…this experiment…" (singular). "…deformation ~~is~~ in impermeable…"

(p. 16, Line 3) "…experiment is primarily…" "…top wall ~~and~~ from the…"

(Figure 10) Call the reader's attention to the fact that scales on axes differ from one plot to the next in a column.

(Figure 11) "…low-permeabil<u>ity</u> material…"

(p. 17, Line 12) "…~~reduction~~…"

(Figure 12) "…The ~~established~~ gradient in fluid pressure thus established ~~pulls~~ forces…"

(p. 17, Line 15) "…contacts ~~is~~ in the DEM is determined…"

(p. 17, Lines 4-20) This seems like a long paragraph to explain something that is already pretty clear and also well understood by most of your readers. It could probably be reduced to about 5 lines.

(p. 17, Line 26) "…which alternately slightly weaken…"

(p. 18, Line 6) "…zone in cases…" Delete comma

(p. 18, Line 19) "…deformation ~~of~~ in subglacial…"

(Figures 14 and 15) These figures can be deleted. The description in the text is adequate.

(p. 19, Line 8) "…stagnation ~~ice flow~~…" "stagnant ice flow" is a redundant. If ice is stagnant there is no flow.

(p. 19, Line 16) If clay particles are added to the water, it will be more viscous. This brings up the old debris-flow problem: what is the fluid and what is the matrix?

(p. 19, Line 19) "…deformed at a constant rate. Changes…"

(p. 19, Line 22-23) "…sediment dilation cause a volumetric contraction in the granular phase…" Confusing. Do you mean the grains are getting compressed elastically? If a sediment dilates, it does not occupy less space.

(p. 19, Line 26) "…perfectly plastic…"

(p. 20, Line 5) I don't remember 732 m/a being mentioned previously.

(p. 20, Line 11) "…millimeter-to-centimeter…" Isn't it more common to go from smaller to larger?

(p. 20, Line 15) "…These temporal…"