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Interactive comment on "DebrisInterMixing-2.3: a Finite Volume solver for three dimensional debris flow simulations based on a single calibration parameter – Part 1: Model description" *by* A. von Boetticher et al.

Anonymous Referee #1

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This paper aims to present a three-dimensional fluid dynamic solver to simulate debris flows as a mixture of two phases. As an advantage to the existing models, the authors mention that there is a single free model parameter that needs to be calibrated. Simulation is based on the Volume Of Fluid (VOF) method and follows the software OpenFOAM within the framework of a single cell-averaged Navier-Stokes equation for incompressible flow. Granular phase is said to be modelled by a Coulomb-Viscoplastic model that represents the pressure-dependent flow behavior, and the Herschel-Bulkley model that is reduced to one-parameter model is used as the rheological equation for the interstitial fluid. The authors argue that the cost of the proposed computational program is low as compared to drag-force based multiphase models and that the depth-averaging is not necessary and complex three-dimensional flow structures can be simulated. There are some important aspects in the manuscript. This includes: P 6351: "The approach aims to link the knowledge of field experts for estimating the release volume and material composition with recent advances that account for complex flow phenomena using three-dimensional computational fluid dynamics." This is appreciable.

Nevertheless, with regard to a mixture debris flow modelling, the manuscript is weak from a scientific point of view. The rheological models are already existing in the literature both for the solid and fluid. So does the basis for the computational method and the CFD software. Therefore, this manuscript could not present substantial advancement in modelling debris flows.

Title: It is not clear why it is called "DebrisInterMixing-2.3"

P 6351:

The authors seem to discuss and criticize lots of existing models but without specifically mentioning/referring a single model. It is mentioned that "the inhomogeneous mixture of gravel and fine material brings about interactions of granular flow and viscous forces ... ." Which means drag is important. Nevertheless, the final model utilized in this paper is effectively single phase and the drag force is neglected. Further it mentions: "In addition, the interactions between the granular and viscous phases, and the dynamic change in granular and viscous concentrations during the flow process, limit simple models to the narrow range of simulations that they have been calibrated for, where the fitted parameters account for these interactions." But, as is commented later, the models presented here do not, and in fact cannot, deal with "dynamic change in granular and viscous concentrations during the flow process".

It is quite confusing to mention here that the MS deals with "improved three-phase modeling approach". Because the numerical model presented here is effectively single phase bulk model, and that it cannot simulate solid and fluid dynamics separately, dynamically evolving fractions of solid or fluid together with the dynamic pressure evolution as a field variable. Also, it is not appropriate to say ambient air as an extra phase in the system. Furthermore, as also discussed by the authors later, as the density and viscosity of the air is negligible as compared to those values of interstitial fluid in the debris mixture, considering ambient air (calling it a third phase), which has no extra mechanical consequence in the flow dynamics, is of little, or no use.

P 6352:

"We allow interactions of both rheologies": Phases would interact, not the rheologies. There are several such improper use of terminologies.

"Numerical costs are kept reasonable by using the Volume of Fluid method (Hirt and Nichols, 1981) such that only one Navier-Stokes equation system is solved for all three phases. We calculate the viscosity and density of each grid cell as a concentration-weighted average between the viscosities of the phases that are present in the cell." It is fast. But ,the main deficiency lies in loosing the physics of the two phase nature of debris mixture by taking such mean values. This is the major drawback of the approach adopted here, both from the rhelogical and computational pint of view. This effectively means that simulations are made only for the single phase bulk material as the present method cannot simultaneously compute physically appropriately the phases and phase velocities plus the associated dynamic pressure.

Further the MS mentions: "Phase interaction is reduced to this averaging of density and viscosity with the aim to avoid the standard approach of phase coupling by the use of drag force models." This way the authors loose the physics of complex two phase flows.

"The drag between non-spherical grains and non-Newtonian fluids is still not well understood and would lead in our case to a model with a high number of unknown param-

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eters.” It is true that drag is a complex phenomena in a debris flow for which the relative phase velocities are non-zero, and the interstitial fluid most probably is non-Newtonian. Nevertheless, we should try to understand the real and important physics of flow, deformation and interactions between phases rather than neglecting or avoiding this. The recent debris flow modelling trend is trying to address these challenges.

“The central assumption for concentration-weighted averaging is that the local velocity of the gravel is about the same as the velocity of the surrounding fluid.” This may be a good approximation for very limited debris flows, e.g., with very low water content. But in general this is not a valid assumption for natural debris flows in which the solid and fluid velocities can evolve differently depending on flow configurations and underlying physics. Therefore, again, the manuscript looses the real physics of two-phase debris flows. By assuming zero relative velocity the authors seem to only consider the flow of a bulk mixture. So, where are the phase effects?

P 6353:

“The assumption of equal velocities of both phases in one cell leads to a constant distribution of phase concentrations over the entire flow process.”: So the approach adopted here could be something of interest for ‘practical’ purpose as the authors often mention, but clearly does not follow the reality of two phase debris flow. There have been substantial recent research works on two phase debris flows with non-zero relative velocity between phases and other higher order interacting terms and advanced physics of flow. This aspect has not been mentioned in the present paper.

“Nevertheless, this assumption avoids the need to model the drag forces between gravel and interstitial fluid, while still accounting for the pressure-dependent flow behavior of the gravel in combination with the shear-dependent rheology of the slurry.”: Again, authors are avoiding lots of important physics without proper justification.

In second paragraph, the terms ‘two-phase’ and ‘non-Newtonian’ are not clear/not properly used. For example, it is not clear from the MS how the fluid component is

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treated as a non-Newtonian fluid. What makes it a non-Newtonian?

“But instead of solving Navier-Stokes equations for each phase coupled by drag models, we apply the numerically more efficient method of Iverson and Denlinger (2001b) and treat the debris flow material as one mixture with phase-averaged properties described by a single Navier-Stokes equation. The resulting reduction in numerical costs allows us to model the three-dimensional momentum transfer in the fluid as well as the free-surface flow over complex terrain and obstacles.”: The method presented here is cheap, but this clearly lacks the major physical aspects as explained (in previous comments and) in the recent developments in two phase debris flow modelling.

P 6355:

“C is the volumetric solid concentration of the mixture”: in reality this should be a dynamically evolving field quantity. But here it seems to be a constant parameter. Or, at least it is not clear.

Equation (4): It is not clear how to determine/obtain the value of the free parameter tau_{00}. Instead the authors mention that “the remaining free parameter which we use to account for the grid size dependency of the shear rate. We recommend a value of tau_{00} = 30Pa as a starting point for calibration.”. This is not justified. And how to determine the rheological parameter from grid size?

P 6356:

2nd paragraph: Are you using (1) or (2) then? Confusing! (1) has been used in debris flow modelling for a long time with much more physical explanation than (2). For example, what is the physical meaning of the free parameter tau_{00}? We should not just recommend some values of a free parameter without clearly exploring its physics and some reasonable justifications.

Equation (6): Is D deformation-rate for solid or for the bulk mixture? If it is for the solid, how does it evolve with the solid velocity field as the solid and fluid velocities cannot be

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distinguished in the present model/method? Similarly, what is p, solid, or fluid or the mixture pressure?

Also, it is not mentioned which BCs are used. Because 3D simulations of mixture with solid phase require very complex BCs.

P 6358:

“The assumption of negligible velocity differences between the gravel particles and the slurry within a finite-volume cell allows the solution of an averaged Navier-Stokes equation for the three phases air, gravel and fluid.”: This is not a realistic assumption for debris flow. It can be negligible for some limited situations, but not in general.

P 6359:

2nd paragraph: The MS does not mention the need, and where it is needed, of full dimensional simulation of granular and debris flows as there are several pioneering contributions available in the literature.

P 6360-61:

Equation (10) and (13):

(10) is the momentum equation for fluid, (13) is the advection (transport) equation for the phases (diffusion is neglected). There are many surprising things in these equations:

- Momentum equations (which are considered only for fluid) include only pressure and viscous forces, but no other forces are included.

- It is not clear, not mentioned which momentum equations are used for solid, and if done at all, how are they coupled?

- Phase interactions and inter phase momentum transfer is a very important and basic concept in mixture flows. But here, there is no phase interactions in the momentum

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equations.

- Concentrations are only advecting with the bulk (or the fluid) velocity. So, the dynamics of the particle (or the solid phase) is neglected, or at least not clear how it is included. Such a situation is typical of very dilute flows with negligible interparticle contacts/collisions and no-frictions. This is most probably not the scenario in debris flow.

- Diffusion of the phases, which is an important process in mixture flows, are neglected here. This avoids the possible mixing mechanism between phases.

- As can be inferred from equations in Fig. 4, there is only a passive, and very weak connection between the phases via cell-averaged bulk kinematic viscosity. Otherwise, the phases (solid and fluid) do not recognize and do not talk to each other that would be required in exchanging the momentum between phases. There must be sufficient interactions (including drag, etc.) between phases that must be included in momentum and transport equations. This has not been done here. This cannot be justified physically.

So, as it stands now, the model developed and used here is weak as this cannot appropriately/sufficiently represent the physics of particle fluid mixture debris flow. Consequently, numerical results presented in part II also lack physical significance.

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