A three-equation shallow-flow model for viscoplastic fluids. Application to the simulation of natural hazards

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Natural hazards such as wet snow avalanches or mud flows involve free-surface flows of yield-stress materials. Some of these phenomena could be considered as Herschel-Bulkley fluid flows. A new shallow-flow model for this type of material is derived with a consistent asymptotic method in order to simulate disaster events like a dam break upon an inclined topography. The development of the model is based on two steps. At first, the variables of the primitive equations are expanded up to the first order of accuracy both in the sheared and the pseudo-plug layers. A specific regularization1 of the rheology is used [1], allowing us to implement a regular perturbation method in the whole domain. However, unlike in classical regularization methods, the material is here characterized by a true yield stress, with a perfectly rigid behavior below the yield point. The expansions thus built provide a smooth velocity field and show a good agreement with experimental data. In the second step, the mass, momentum and energy balance equations are averaged over the depth of the flow. This results to a fully hyperbolic model of three equations for the fluid depth, the average velocity, and a third variable named enstrophy related to the internal shearing of the flow. This model admits an exact work energy theorem. A dam break problem upon an inclined plane is simulated. It is found that the propagation of the fluid front after the dam break demonstrates three main regimes : an inertia-dominated regime, a plasticity-dominated regime, and final stoppage. Comparison with experimental results shows a good agreement, especially for the inertia-dominated regime and for the material shape after stoppage.

[1] D. Denisenko, G. Richard, G. Chambon. *A consistent three-equation shallow-flow model for Bingham fluids.* Journal of Non-Newtonian Fluid Mechanics, **321**, 2023.

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