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A Variational Treatment of Energy Dissipation in Dense Gravity Flows

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We first write energy dissipation functionals of dense gravity flows $\Phi(u_0, u_p)$ in terms of the slip velocity $u_0$and plug velocity u_p. The dissipation functionals are formulated such that sliding friction at the basal surface and internal viscous deformation are both included in the formulation. Bingham and Bagnold type flows with Voellmy-fluid slip conditions are investigated. Using the steady state mass continuity condition Γ as an additional flow constraint, we then solve the variational problem $\delta(\Phi + \lambda\Gamma) = 0$to find the velocity structure (slip velocity and velocity profile) that minimizes the energy dissipation. This state is a steady state where the energy dissipation is in balance with the gravitational work rate. However, we find two other interesting features. Firstly, the state of minimum energy dissipation is a product of two competing mechanisms: basal sliding and internal deformation. The slip velocity regulates the dissipation in both processes. Secondly, there exist constitutive formulations where the flow system is constrained outside the absolute dissipation minimum. This is a violation of a general law of irreversible thermodynamics, the principle of minimum entropy production. The variational treatment allows the investigation of flow stability with respect to fluctuations in the internal velocities. In a final step we show that the constitutive models are all stable in the sense of Lyapounov.