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A model for three-phase debris flow with novel virtual mass forces

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Frictional and viscous resistance, and drag and virtual mass forces are the most important mechanical aspects of mixture mass flows including avalanches, landslides, debris flows and particle-laden floods. When the relative motions and relative accelerations are substantial to high, drags and virtual mass forces become dominant components of mixture rheology. However, the mechanics and rheology of virtual mass force are very poorly understood, and thus, due to its complexity, the virtual mass force is often ignored or only included empirically in multi-phase flow simulations. Here, we construct a first-ever analytical, full and explicit expressions for the virtual mass coefficients in true three-phase mixture consisting of coarse-sediment, fine-sediment and viscous fluid, constituting a typical debris flow (Pudasaini and Kattel, 2019). Connecting the distinct phases, three fundamentally different virtual mass forces emerge as analytical functions of phase-fractions, phase-densities, and the capacity of the coarse material to hold the fine particles and the viscous fluid. Emergence of the virtual mass force coefficients induced enhanced viscosities, phase fractions, drags, viscous stresses and gravity forces of the coarse-solid and fine-solid further highlight the mechanical strength and importance of the newly constructed multi-phase mass flow model. The new model reduces to the two-phase mass flow model by Pudasaini (2012) as a mixture of solid particles and viscous fluid, and to Cook and Harlow (1984) for a mixture of gas bubbles and fluid. Depending on the local distribution of the viscous fluid and the fine particle concentrations, the new model can be applied to dilute to dense flow regimes of the mixture, and thus it covers the whole spectrum of the mixture rheology, including the coarse-, and fine-solid, and the fluid limits. Some analytical/numerical solutions of the new model will be presented.

References:

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