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Tsunami Generated by a Two-Phase Submarine Debris Flow

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The general two-phase debris flow model proposed by Pudasaini (2011) is employed to study subaerial and submarine debris flows, and the tsunami generated by the debris impact at lakes and oceans. The model includes several essential physical aspects, including Mohr-Coulomb plasticity for the solid stress, while the fluid stress is modelled as a solid volume fraction gradient enhanced non-Newtonian viscous stress. The generalized interfacial momentum transfer includes the viscous drag, buoyancy, and the virtual mass. The generalized drag covers both the solid-like and fluid-like contributions, and can be applied to linear to quadratic drags. Strong couplings exist between the solid and the fluid momentum transfer. The advantage of the real two-phase debris flow model over classical single-phase or quasi-two-phase models is that by considering the solid (and/or the fluid) volume fraction appropriately, the initial mass can be divided into several (even mutually disjoint) parts; a dry (landslide or rock slide), a fluid (water or muddy water; e.g., dams, rivers), and a general debris mixture material as needed in real flow simulations. This offers a unique and innovative opportunity within a single framework to simultaneously simulate (a) the sliding debris (or landslide), (b) the water lake or ocean, (c) the debris impact at the lake or ocean, (d) tsunami generation and propagation, (e) mixing and separation between the solid and the fluid phases, and (f) sediment transport and deposition process in the bathymetric surface.

The new model is applied to two-phase subaerial and submarine debris flows. Benchmark numerical simulations reveal that the dynamics of the debris impact induced tsunamis are fundamentally different than the tsunami generated by pure rock avalanche and landslides. Special attention is paid to study the basic features of the debris impact to the mountain lakes or oceans. This includes the generation, amplification and propagation of the multiple strong and bore-type tsunami waves and run-ups in the coastal lines, and debris slide and deposition at the bottom floor. Strong debris shock waves are generated that travel upstream. Once the debris supply ceases, the shock front is diffused. The model analysis also includes mixing and separation of phases, including inter-phase mass and momentum exchanges and generation and interactions of solid and fluid waves. The state of the solid volume fraction governs the evolution of the fluid extra stress and thus effectively dominates the entire flow dynamics. So, the actual knowledge of the solid volume fraction is essential for the prediction of the turbidity currents, sediment transport and deposition in the subaerial and submarine environments. Applications of this model include (i) the sediment transport on hill slopes, river streams, hydraulic channels (e.g., hydropower dams and plants); lakes, fjords, coastal lines, and aquatic ecology; and (ii) submarine debris impact and the rupture of fiber optic, submarine cables and pipelines in ocean floor, and damage to offshore drilling platforms. The Phase-Froude numbers (the solid and fluid Froude numbers) are introduced that change drastically as the debris mass hits the fluid dam. The Phase-Froude numbers can be subcritical or super-critical, suggesting that the tsunami may be following or preceding the wave generating submarine slide and thus enhancing or reducing the tsunami waves. It is observed that the submarine debris front speed can be faster than the tsunami wave speed. This information can be useful for the early warning strategy in the coastal regions. These findings substantially increase the dynamical understanding of complex multi-phase systems and flows, allowing proper modeling of landslide and debris induced tsunami, the dynamics of turbidity currents and sediment transport, with associated applications in hazard mitigation, geomorphology and sedimentology.