Experimental validation of a two-layer model for pyroclastic density currents

*Hiroyuki A. Shimizu[1], Takehiro Koyaguchi[2], Yujiro J. Suzuki[2], Brosch Ermanno[3], Gert Lube[3]

1. National Research Institute for Earth Science and Disaster Resilience, 2. Earthquake Research Institute, The University of Tokyo, 3. Massey University

During explosive volcanic eruptions, a hot mixture of volcanic particles and gas is ejected from the volcanic vent and can flow along the ground surface as a pyroclastic density current (PDC). A PDC is generally characterized by a strong density stratification; it is composed of a dilute current (particle volume fractions $\Phi < 10^{-2}$) over a dense basal current ($\Phi \sim 10^{-1}$). The dynamics of such strongly stratified PDCs can be investigated by a two-layer depth-averaged model (Shimizu et al., 2019, J. Volcanol. Geotherm. Res., 381, 168-184). In this study, we have validated our two-layer model by comparison with two experiments: (1) the pyroclastic-flow eruption large-scale experiment (PELE; Lube et al., 2015, J. Geophys. Res., 120, 1487-1502) and (2) a granular-flow experiment (GFE; Girolami et al., 2008, J. Geophys. Res., 113, B02202).

In the PELE, an experimental current is generated by the controlled gravitational collapse of a hot aerated suspension of particles and air from an elevated hopper into an instrumented inclined channel. A well-defined dataset has been newly obtained from the PELE for the purpose of validation and benchmarking. In the experiment, a strongly stratified current (consisting of a dilute turbulent suspension flow and a basal bedload region) flowed into the inclined channel and the distal horizontal channel, and it produced the deposits by progressive aggradation of particles at the base during flowing. Numerical simulations using our two-layer model were conducted under the same condition of the experiment. The numerical results for the upper dilute current (e.g., front position and thickness) agree well with the experimental data for the dilute suspension flow. The numerical results for the dense basal current and the deposits also agree with the experimental data, when the volume fraction in the dense basal current (Φ_b) is set to the value observed in the experiments (the time-averaged value for the bedload at an upstream point; i.e., $\Phi_b = 0.02$) and the constant deposition speed at the base of the dense current (D) is tuned to 3.7×10^{-4} m/s.

In the GFE, a stationary fluidized mixture in the rectangular-lock domain was released at time $t = 0$, flowed into the horizontal channel, and produced the deposits by progressive aggradation during flowing. Numerical simulations using the basal-layer model in our two-layer model were conducted under the same condition of the experiment. The numerical results agree well with the experimental data for the flow-front position as a function of time and the final deposit distribution, when Φ_b is set to the initial value measured in the experiment (i.e., $\Phi_b = 0.42$) and D is tuned to 1.7×10^{-2} m/s.

The above two results ($D = 3.7 \times 10^{-4}$ m/s and $\Phi_b = 0.02$ for the PELE; $D = 1.7 \times 10^{-2}$ m/s and $\Phi_b = 0.42$ for the GFE) imply that the physics is different between the bedload region observed in the PELE and the granular flow observed in the GFE. The value of D for the GFE can be quantitatively explained by the hindered-settling model for $\Phi_b = 0.42$. That for the PELE, on the other hand, is substantially smaller than the value predicted by the hindered-settling model ($D \sim 10^{-2}$ m/s for $\Phi_b = 0.02$). The small deposition speed (i.e., $D = 3.7 \times 10^{-4}$ m/s) and the small particle volume fraction (i.e., $\Phi_b = 0.02$) in the PELE are consistent with the qualitative observation that saltating/rolling/sliding of particles occur in the bedload region owing to a complicated combination of deposition and erosion processes (i.e., some particles do

not simply settle to the bottom) in this experiment. These results indicate that the dynamics and sedimentation processes of the dense basal layer depend on the source condition and/or the presence of the slope. A sophisticated dynamical model considering the combination of deposition and erosion processes may reproduce the experimental data both for the bedload region in the PELE and the granular flow in the GFE.

Keywords: Pyroclastic density current, Ignimbrite, Numerical simulation, Experimental validation, Two-layer model, Granular flow

