# Dynamic Interaction Between a Two-phase Submarine Landslide and a Fluid Reservoir

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## 1 Introduction

Subaerial and submarine landslides and debris flows are very important, but also very dangerous sediment transport mechanisms. Examples include sediment transport in hill slopes, in hydraulic channels and submarine environments (Miller, 1960; Miller, 1964; Fine et al., 2005; Haugen et al., 2005; Liu et al., 2005; Masson et al., 2005; Abadie et al., 2010; Foerster et al., 2010; Geersen et al., 2011; Pudasaini and Miller, 2013). These are effectively two-phase flows of solid particles mixed with fluid (Pudasaini and Hutter, 2007; Pudasaini et al., 2005; Pudasaini, 2011,2012). Accurate knowledge of the distribution and evolution of the solid and the fluid-phases are very important from the environmental and industrial point of view including the huge landslides in the coastal and mountain areas, and particle transport in mountain lakes, rivers, reservoir and hydro-electric power plants (Pudasaini and Miller, 2012a,b). The information of submarine debris wave speed can be useful for the design of early warning strategies in the coastal regions (Pudasaini, 2013).

## 2 A real two-phase submarine landslide

Previous findings substantially increase our understanding of complex multi-phase systems and multi-physics and flows, and allows for the proper modeling of landslide and debris induced tsunami, the dynamics of turbidity currents and sediment transport, and associated applications to hazard mitigation, geomorphology, and sedimentology. Here, we apply the general two-phase debris flow model (Pudasaini, 2012) and advance further by simulating three-dimensional subaerial and submarine debris flows. With an innovative and unified approach, we analyze the mechanics of complex wave generation and interactions between the solid and the fluid phases in the lakes, reservoirs and hydraulic channels. This includes the tsunami generated by the debris impact at reservoirs, lakes and oceans (Pudasaini and Miller, 2012b; Pudasaini, 2013). We focus on the generation, amplification and propagation of super tsunami waves and run-ups along coastlines, debris slide and deposition at the bottom floor, particle transport in hydraulic channels, and the integrity of the reservoir dams, embankments and hydroelectric power plants. Figure 1 shows a simulation of a two-dimensional and two-phase submarine landslide and the associated tsunami wave as generated by the landslide impact at a reservoir.

## 3. Concluding remarks

The simultaneous dynamic simulation of the two-phase, three-dimensional subaerial debris flow, the resulting tsunami generation and propagation upon debris impact at the reservoir, the subsequent submarine debris flow, and the entire analysis of all three types of waves and their complex interactions are studied by applying a generalized two-phase debris flow model (Pudasaini, 2012), and are simulated together with a high resolution shock capturing numerical scheme (Pudasaini and Hutter, 2007). We analyze in detail on how the subaerial debris mass penetrates the fluid reservoir and finally how it moves and deposits on the bottom of the reservoir basin (Pudasaini and Miller, 2012b; Pudasaini, 2013). Our results can further be applied to properly analyze the stability of reservoir dams, embankments and slopes in response to the fluctuation of the water level (due to landslide impact) in the reservoir and lakes which plays a crucial role in the evolution of the pore-fluid pressure and seepage conditions. Similarly, our model and computational technique can be applied to simulate sediment transport in hydro-electric power-plants and to advanced estimation of erosion on the power generating turbines

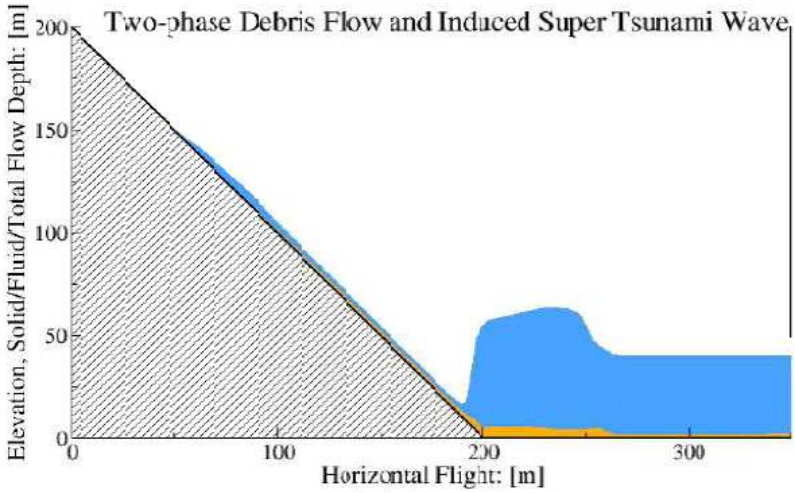


Fig. 1: Two-phase subaerial debris flow hits a fluid reservoir, generates tsunami wave, and a submarine debris wave continues to slide down. Orange and blue colors indicate volume fractions of solid and fluid. Initially, the reservoir consists of 2% solid, and the initial debris mass consists of 50% solid and 50% fluid. The tsunami wave is amplified, leading to an increasing hydrodynamic impact vacuum. There are three complex flows taking place simultaneously: a subaerial debris flow in the upstream, a submarine debris flow in the downstream and at the reservoir floor, and a surface tsunami wave (Pudasaini and Miller, 2012b).

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