Modeling Muddy Flows

A theoretical model of a surface-wave instability matches observations of a muddy debris flow in an Alpine valley.

By Marric Stephens

Last month, a collapsing glacier triggered a landslide that destroyed 90% of the Swiss village of Blatten. A few kilometers from Blatten, the Illgraben valley experiences debris flows multiple times a year, although those flows are muddier and are set off by rainfall or snowmelt. Xiannan Meng and colleagues at Dalian Maritime University in China have developed a set of equations to describe muddy debris flows and have compared their solutions to an especially-well-documented event that occurred in Illgraben in 2013 [**1**]. In particular, the researchers found that their model captures the dynamics of roll waves, a fluid-mechanical instability that causes surface waves to propagate in the direction of the flow.

A flow becomes susceptible to the roll-wave instability when its Froude number—the ratio of inertial to gravitational forces acting on the flow—attains a certain characteristic value. This value has been determined for dry granular flows and pure liquid flows. But mixed flows are less well characterized, especially muddy debris flows, which are saturated with water, and whose solid fractions are dominated by small grains.

Credit: Swiss Federal Research Institute WSL

To recreate the 2013 Illgraben event, Meng and colleagues implemented their model in a numerical simulation that reproduced the local topography. They triggered the roll-wave instability by adding small, randomly distributed bumps to the base of the flow and then observed the way the ensuing roll waves developed, propagated, and merged. Having found a good match with the real-world event, they inferred from their model that the instability is triggered in muddy flows at a Froude number slightly higher (corresponding to a faster flow) than that of a dry granular flow but below that of a pure water flow.

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REFERENCES

1. X. Meng *et al.*, "Roll-wave instability and evolution of single-phase debris flows," **Phys. Rev. Fluids (2025).**