Geophysical Research Abstracts
Vol. 14, EGU2012-7906, 2012
EGU General Assembly 2012

Dynamic modelling of debris flow erosion and deposition with application to the USGS debris flow flume experiments

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The dynamics of a debris flow can be significantly influenced by erosion and deposition processes during an event because volume changes have a strong influence on flow properties such as flow velocity, flow height and runout distance. It is therefore worth exploring how to include these processes in numerical models which are used for hazard assessment and mitigation measure planning. However, the mechanism that drives the erosion of material at the base of a debris flow, is still under debate. There are different processes attributed to erosion: it has been proposed that erosion is caused by stresses due to granular interactions at the front, which strongly depend on particle size, transmission of mean basal shear stresses to the bed or excess pore fluid pressure.

Because there is no definitive solution for a general erosion model, we implement different erosion relationships accounting for different entrainment types in a numerical model and test its influence on the flow behavior. We use a 2D numerical model (RAMMS), based on the shallow water equations, employing the Voellmy friction relationship. Snow avalanche data indicate a simple velocity-driven erosion rate. Ice-avalanche simulations, on the other hand, showed that a correlation of erosion with velocity does not lead to satisfying results (too high entrainment in the tail) and a correlation with flow height combined with velocity (momentum) is preferably applied. The momentum-driven relationship enhances the entrainment at the flow front. However, these laws do not consider processes on smaller scales, such as particle fluctuations within the flowing mass. Therefore, we consider an erosion relationship based on an extended Voellmy friction model, which employs an additional equation for the energy conservation. The energy equation is a measure for the random kinetic energy (RKE, equivalent to granular temperature) produced by the random movement of particles in a debris flow. In this model friction is dependent on the production of RKE and is decreasing with increasing RKE. The amount of energy produced in the system might be a useful indicator for the erosion rate.

We first calibrated the Voellmy friction model and the extended Voellmy model (including RKE) without including erosion processes by comparing the results with the USGS flume experiments (Iverson et al., 2010. The perfect debris flow? Aggregated results from 28 large-scale experiments, J. Geophys. Res., 115, F03005, doi:10.1029/2009JF001514), which provide comparison of flow velocities, flow heights and runout distances. The Voellmy-simulations fit the dynamic parameters (velocities and heights) quite well, while the runout distance and the final deposit geometry is better reproduced by the extended Voellmy model. This indicates that the particle fluctuations may play a major rule in debris flow systems. Both models including erosion processes are then compared with entrainment experiments performed in the USGS debris flow flume (Iverson et al., 2010. Positive feedback and momentum growth during debris-flow entrinment of wet bed sediment, doi:10.1038/NGEO1040). Flow properties, such as velocity, height and runout distance can be calibrated, but there is no data available on the dynamics of erosion. Therefore, we compare the different erosion relationships relative to each other.

The simulations performed with the debris flow flume data allow us to study the details of the flow behavior including different entrainment processes. In the future we would like to compare the models with natural debris flow events from the Illgraben debris flow site of which we have data from an observation station including flow parameters and erosion rate measurements.