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Developing an Experimental Simulation Method for Rock Avalanches: Fragmentation Behavior of Brittle Analogue Material

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Gravitational mass movement on earth and other planets show a scale dependent behavior, of which the physics is not fully understood. In particular, the runout distance for small to medium sized landslides (volume $< 10^6 m^3$) can be predicted by a simple Coulomb friction law consistent with a constant kinetic coefficient of friction at the landslide base. This implies that the runout can be considered independent of volume. Large volume landslides (rock avalanches), however, show a dependence of runout on volume. This break in scaling behavior suggests that different dynamics control small and large landslides/rock avalanches. Several mechanisms have been proposed to explain this scale dependent behavior, but no consensus has been reached.

Experimental simulations of rock avalanches usually involve transport of loose granular material down a chute. Though such granular avalanche models provide important insights into avalanche dynamics, they imply that the material fully disintegrate instantaneously. Observations from nature, however, suggests that a transition from solid to “liquid” occurs over some finite distance downhill, critically controlling the mobility and energy budget of the avalanche. Few experimental studies simulated more realistically the material failing during sliding and those were realized in a labscale centrifuge, where the range of volumes/scales is limited. To develop a new modeling technique to study the scale dependent runout behavior of rock avalanches, we designed, tested and verified several brittle materials allowing fragmentation to occur under normal gravity conditions.

According to the model similarity theory, the analogue material must behave dynamically similar to the rocks in natural rock avalanches. Ideally, the material should therefore deform in a brittle manner with limited elastic and ductile strains up to a certain critical stress, beyond which the material breaks and deforms irreversibly. According to scaling relations derived from dimensional analysis and for a model-to-prototype length ratio of 1/1000, the appropriate yield strength for an analogue material is in the order of 10 kPa, friction coefficient around 0.8 and stiffness in the order of MPa.

We used different sand (garnet, quartz) in combination with different matrix materials (sugar, salt, starch, plaster) to cement it. The deformation behavior and strength of the samples was tested using triaxial compression tests at atmospheric confining pressures. Proper material properties were obtained using well-sorted, well-rounded, medium grained quartz sand with gypsum plaster as matrix. The favored analogue material is produced by thoroughly mixing the quartz sand with gypsum and water. Afterwards, sufficient time is given to allow cementation by the gypsum. The material typically exhibits elastic deformation up to 0.3% strain and additionally <0.1% ductile strain, up to failure. Youngs modulus is found to be in the order of 4 MPa. Yield strength is a non-linear function of the concentration of gypsum in the mixture. Material with 1 wt% gypsum is found to have an appropriate strength for labscale modeling of rock avalanches.

To verify the suitability of the new analogue material to study fragmentation during mass movement at labscale we present preliminary results of experimental simulations using loose sand and the sand-plaster mixture. We model rock avalanches at labscale by releasing the material down a plane of up to 2000 mm and slopes varying between 30 of 60 degrees. The experiments are monitored with a 250 Hz digital video camera. The images are analyzed using particle image velocimetry to study the surface dynamics of the labscale avalanches. Discrete element modeling is planned to benchmark our results and validate the simulation method.