Geophysical Research Abstracts, Vol. 7, 08228, 2005
SRef-ID: 1607-7962/gra/EGU05-A-08228

Modeling flow-regime transitions using an extension of the Norem-Irgens-Schieldrop rheological model

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The rheology at the basis of the Norem–Irgens–Schieldrop (NIS) model combines frictional, viscoplastic, viscoelastic and collisional material behavior. The latter implies dispersive normal and shear stresses growing with the square of the shear rate. According to the model, the normal stress component perpendicular to the flow plane may reach or exceed the overburden load at high velocities, i. e., on sufficiently steep slopes. Under that condition, no stress is transmitted by enduring particle contacts, the material is fluidized and expands. We propose to identify the low-velocity flow with the dense core of snow avalanches and the high-velocity regime with the more dilute layer variably termed “zone of light flow”, “saltation layer”, “resuspension layer” or “fluidized layer” in the literature. Over the past twenty-five years, strong experimental evidence has accumulated for the existence of this fludized layer.

In its presently implemented form, the NIS model does not allow for density changes and thus does not explicitly recognize the particular properties of the fluidized flow regime. We supplement the rheological model with an isotropic dispersive pressure term and impose certain inequalities on the rheological parameters to prevent unphysical negative longitudinal and lateral pressures from arising at high shear rates before fluidization. In order to describe the expansion of the fluidized material, the density dependence of the rheological parameters needs to be specified. For intermediate densities, we propose simple relations derived from the assumption of inertial momentum

transport. This implies proportionality between dispersive shear and normal stresses, as found e. g. in computer simulations, but would make the material dilute indefinitely once fluidization is reached. At low densities, however, rarefaction effects should be taken into account. We discuss preliminary proposals for addressing this point and show which effects are responsible for the elevated velocities attained by a fluidized flow in comparison with a non-fluidized flow under the same conditions.

Two further points have to be solved when implementing the extended NIS rheology in an avalanche flow model: (1) Preliminary estimates suggest that fluidization should not be reached but in very steep slopes, yet most medium-size to large dry-snow avalanches appear to have a fluidized front. We conjecture the combined effect of the stagnation pressure at the snout of the flow and significant underpressure at the upper surface of the head to be responsible for a limited flow-regime transition. (2) The local (or depth-averaged) density must be specified as a function of the flow variables. We propose an evolution equation based on the momentum balance in the direction normal to the bed, thus departing from the customary assumption of strictly hydrostatic pressure distribution.