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Intense transport of bed load – modeling based on experimentally observed flow structure

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A modeling approach is discussed which enables to predict characteristics of steady uniform open-channel flow carrying a large amount of sediment (bed load). The approach considers a layered structure of the sediment-laden flow and employs conditions at layer interfaces to evaluate the flow slope, depth, the thickness of the layers and flow rates of both the sediment and sediment-water mixture. It is based on experimental observations obtained for lightweight granular materials in a laboratory tilting flume. Besides visual observations of a development of the layered structure of the flow, detailed profiles of the longitudinal velocity were collected together with integral characteristics of the flow (depths and slopes, flow rates) in the flume. Values of the grain velocity and concentration at the interfaces were determined from the measurements and observations.
In the upper plane bed regime of bed load transport, the flow structure appears to be composed of up to three distinct layers (water layer, linear collisional layer and dense sliding layer). Depending on a value of the bed Shields parameter (and associated flow conditions) the number of layers may change and the thicknesses of the particular layers vary. It appears that collisional layers in flows in which they dominate the flow depth (typically Shields bigger than 1) exhibit a virtually constant value of the collisional-layer Richardson number. Velocity and concentration profiles across the collisional layer can be considered linear. At the bottom of the flow, the Coulomb yield criterion with the assumption of the zero fluid contribution balances the bed shear stress applied by the flowing mixture of water and sediment. These features are employed in the discussed modeling approach and lead to a depth-averaged flow model composed of a set of balance and constitutive equations. A kinetic-theory based formula for granular shear stress at the bottom of the collisional layer is added to close the set of model equations.