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Phase classification and transition of laboratory debris flows over a rigid bed based on the relative flow depth and friction coefficients

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The characteristics of debris flows vary widely, corresponding to the wide range of natural conditions under which debris flows occur. Many flume experiments have been conducted to validate mathematical and physical models in studies on the individual flow types of debris flows. Experimental data in one study are often not usable in another as the proposed models generally require many different parameters. Indices such as the friction coefficient that require few parameters can be used to compare existing experimental data across a range of studies, although the friction coefficient cannot explain detailed flow properties. In this study, the friction coefficients of debris flows over a rigid bed from several previous experiments were compiled in a preliminary investigation on the classification of phase transitions in debris flows.

The experimental friction coefficient was calculated using compiled experimental data. Suitable experimental data were selected based on the following criteria. First, flume experiments of steady and uniform flows with uniform inclination and constant water-sediment supply from the upper part were listed. Next, experiments over a rigid bed with an almost uniform particle size were selected. The data had to contain particle size, sediment concentration, and the values required to calculate the friction coefficient (i.e., mean velocity, flow depth, and flume inclination). Total experiments analyzed in this study comprised 203 study cases showing sufficient variation with experimental conditions and flow types (e.g., boulder debris flows, sediment-laden flows, hyperconcentrated debris flows, mud flows) for debris flows.

The collected friction coefficients were compared to the theoretical values of the friction coefficients in the relationship with the relative flow depth on the basis of sediment particle size (h/d) under various conditions. The friction coefficients of debris flows with h/d values less than 20 agreed closely with the theoretical value for boulder debris flows derived from the constitutive equations, while the friction coefficients with h/d values in the range 1000-10,000 agreed roughly with the theoretical value for turbulent water flows. The friction coefficients with h/d values of 30-300 exceeded the theoretical value for both debris and turbulent water flows. These intermediate debris flows were observed in experiments involving turbulent mud flows. However, a review of these experiments revealed that they may have included debris flows in which the turbulent structure was not well developed, and could be considered as debris flows in transition from laminar to turbulent flows.

In some of the transitional debris flows, an interface dividing the flow structure into an upper turbulent-flow layer and a lower debris-flow layer was observed as reported for sediment-laden flows. The friction coefficient for transitional debris flows was modeled considering the shift of this interface. The model was able to explain the value of friction coefficients for transitional debris flows. This result supports the idea that the phase transition of debris flows from laminar to turbulent flows can be interpreted as a shifting interface that divides the flow structure. Although the detailed flow structure of debris flows should be examined further, especially in phase transition, the shifting interface is considered an important candidate for the path of phase transition.