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Phase transition in debris flows over a rigid bed

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Constitutive equations for debris flows have been derived from simple models of laminar flow, focusing on the stress structure of internal particles. For debris flows over a rigid bed, however, there is thought to be a transition from laminar to turbulent flow as the flow descends. This study proposes using a Reynolds number defined for debris flows as an index of the debris flow to judge whether the flow is laminar or turbulent. The Reynolds number contains the shear stress derived from constitutive equations as a viscosity term and the viscous sublayer thickness in the debris flow as a representative length term. Defining the critical Reynolds number as 100, by analogy with a viscous sublayer of clear water, debris flows can be categorized according to the ratio of the viscous sublayer thickness to the flow depth. When the ratio exceeds 1, the flow is laminar, and the constitutive equations for debris flows can be applied. When the ratio is sufficiently smaller than 1, the flow is turbulent, and the constitutive equations for debris flows cannot be applied. To confirm this relationship, experiments were conducted in an open channel measuring 10 m long and 0.1 m wide. Several particle sizes (ca. 0.2-3 mm) and channel angles (13 and 17˚) were tested. In experiments, pore pressure distribution in debris flows was measured to judge whether the flow was laminar or turbulent, since pore pressure in laminar debris flows corresponds with that given by constitutive equations, whereas in turbulent flows it corresponds with total pressure. The transition from laminar to turbulent flow was observed when the ratio of the viscous sublayer thickness to the flow depth calculated for the experimental conditions was near 1, supporting application of the Reynolds number to describe the transition in debris flows.