Review Dynamic Modeling of Debris Flows

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Abstract

A debris flow is a flow of sediment-fluid mixture. Four key features in momentum exchange of debris flows are fluid viscosity, turbulence, particle sliding friction, and particle collision. Debris flows were qualitatively classified into six flow regimes, according to the dominance of these key features. Existing rheological models for debris flows in various flow regimes were briefly reviewed. The characteristics of flow velocities for a steady, two-dimensional uniform debris flow in each flow regime were obtained by treating the debris flow as a single-layer uniform mixture. The mixed-layer models and the hydraulics of debris flow were also discussed.

1. Introduction

Debris flow is generally described as the gravity flow of soil, rocks, water and/or air mixture initiated by landslides with high runoff water flow. Its flow properties vary with water and clay content, sediment size and size distribution. The occurrence of debris flow is rather unpredictable and very destructive. Debris flows could move faster than the more common landslides and tend to affect areas at much greater distance from the source of hazard. Debris-flow disaster has been recognized as a critical problem facing the world today, and hence this has resulted in a dramatic increase in the number of studies of debris flow initiation and its flow phenomena. Debris flow is usually treated as the movement of a continuum for simplicity, in spite of the existence of solid particles in it. Since the mixture of debris is treated as a continuum,
the equations of mass and momentum conservation for debris flow are similar to those for general fluid flow.

\[
\frac{D\rho_m}{Dt} + \rho_m \frac{\partial u_k}{\partial x_k} = 0 \quad (1)
\]

\[
\rho_m \frac{\partial u_j}{\partial t} + \rho_m u_k \frac{\partial u_j}{\partial x_k} = \rho_m f_j + \frac{\partial \sigma_{ij}}{\partial x_j} \quad (2)
\]

where \( \rho_m \) is the density of debris mixture and \( \rho_m = (1 - C)\rho_f + c \rho_s \) for saturated debris mixture, in which \( \rho_f \) and \( \rho_s \) are densities of interstitial fluid and the solid particles in the debris mixture, respectively; \( t \) is time; \( x_k \) is the Cartesian coordinates and \( k = 1, 2, \) and \( 3 \), representing \( x, y \) and \( z \) directions; \( u_k \) is velocity components; \( f_j \) is the body-force components; \( \sigma_{ij} \) is the stress tensor in which the first subscript indicates that the stress component acts on the plane \( x_i = \) constant and the second subscript indicates that it acts in the \( x_j \) direction. The stress tensor \( \sigma_{ij} \) is usually expressed as \( \sigma_{ij} = -p \delta_{ij} + \tau_{ij} \), where \( p \) the thermodynamic pressure; \( \tau_{ij} \) is the shear-stress tensor and \( \delta_{ij} \) is the Kronecker delta. Solid particles in debris flow can collide, rub, rotate, and vibrate as they translate downslope. Four key features in momentum exchange of debris flows are fluid viscosity, turbulence, particle sliding friction, and particle collision (Jan, 1992). Therefore, debris flows may exhibit non-Newtonian behavior, and thus rheological models (or constitutive equations) relating stress, strain, time and other variables are needed for debris-flow routing. In the last few decades, attempts to understand the physical processes in debris flow have received considerable attention and various rheological models have been experimentally and theoretically proposed (Bagnold, 1954; Savage, 1984; Shen, 1982). However, most of the models are limited in a two-dimensional debris flow, and each model has its own limit in application. For the sake of simplicity of discussion on the applicability of various