

## A study of methods to estimate debris flow velocity

**Abstract** Debris flow velocities are commonly back-calculated from superelevation events which require subjective estimates of radii of curvature of bends in the debris flow channel or predicted using flow equations that require the selection of appropriate rheological models and material property inputs. This research investigated difficulties associated with the use of these conventional velocity estimation methods. Radii of curvature estimates were found to vary with the extent of the channel investigated and with the scale of the media used, and back-calculated velocities varied among different investigated locations along a channel. Distinct populations of Bingham properties were found to exist between those measured by laboratory tests and those back-calculated from field data; thus, laboratory-obtained values would not be representative of field-scale debris flow behavior. To avoid these difficulties with conventional methods, a new preliminary velocity estimation method is presented that statistically relates flow velocity to the channel slope and the flow depth. This method presents ranges of reasonable velocity predictions based on 30 previously measured velocities.

**Keywords** Debris flow · Velocity · Superelevation · Mitigation · Design

### Introduction

A debris flow is “a mass movement that involves water-charged, predominantly coarse-grained inorganic and organic material flowing rapidly down a steep, confined, preexisting channel” (VanDine 1985). Debris flows are hazardous due to their poor predictability, high impact forces, and their ability to deposit large quantities of sediment in inundated areas. Debris flow mitigation structures may be required to minimize the risk to developments on alluvial fans. Debris flow velocity is an important factor in the design of mitigation structures because it influences the impact forces, run-up, and superelevation of the flow. Debris flow velocities are conventionally back-calculated from previous superelevation events (Johnson 1984) or predicted using flow equations (Lo 2000). A velocity back-calculation from a superelevation event requires an estimate of the bend’s radius of curvature, which is a subjective concept for a natural channel but may be reasonably estimated. A velocity prediction using a flow equation requires the selection of an appropriate rheological model and its material property inputs.

This study investigates the difficulties associated with the use of these conventional velocity methods. Errors associated with the estimation of radius of curvature through different methods are examined, as is the problem with estimating rheological properties through laboratory tests. Velocity, flow depth, and channel slope trends along the paths of debris flows are also investigated, and we propose a new method for preliminary debris flow velocity estimations that avoids the abovementioned difficulties. This method statistically relates flow velocity to the channel slope and the depth of

flow based on 30 previously measured velocities from the technical literature.

### Background

#### Velocity back-calculations

In order to estimate the velocity of a past debris flow, a superelevation event is required. Superelevation refers to the difference in surface elevation, or banking, of a debris flow as it travels around a bend. Higher velocities result in increased banking. If the bend geometry is known, flow velocity can be estimated from superelevation or vice versa. An existing superelevation can be measured from bank levees to estimate the velocity of the flow that formed them. The required height of deflection structures can be estimated by predicting the superelevation from a flow with a given velocity. Based on the results of large-scale flume experiments, back-calculation using superelevation may presently be the most accurate way to estimate debris flow velocity (Iverson et al. 1994). The most commonly referenced method for making this estimation is the forced vortex equation (Chow 1959; Henderson 1966; Hungr et al. 1984; Johnson 1984), which equates fluid pressure to centrifugal force (McClung 2001):

$$v = \sqrt{\frac{R_c g \Delta h}{k b}} \quad (1)$$

where:

- $v$  mean flow velocity,
- $R_c$  the channel’s radius of curvature,
- $g$  acceleration of gravity,
- $\Delta h$  superelevation height (Fig. 1),
- $k$  correction factor for viscosity and vertical sorting, and
- $b$  the flow width (Fig. 1).

The banking angle ( $\beta$ ) can be measured instead of measuring  $b$  and  $\Delta h$ , where  $\beta = \tan(\Delta h/b)$ . In order to account for the slope-normal component of gravity,  $g$  should be replaced with  $g^*$  if the channel slope is greater than  $15^\circ$ , where  $g^* = g \cos \theta$ , and  $\theta$  is the channel slope (Johnson 1984).

Equation 1 assumes that flow is subcritical, the radius of curvature is equal for all streamlines, and every streamline’s velocity is equal to the mean flow velocity (Pierson 1985). Equation 1 was originally derived for water, and thus, the correction factor  $k$  is sometimes applied to account for the viscosity and vertical sorting of particles within debris flows (Hungr et al. 1984). Different studies suggest different values for  $k$  in order to match experimental superelevations to theoretical values. Suwa and Yamakoshi (2000) mention that  $k$  is usually greater than or equal to 1. VanDine (1996) stated that  $k$  may vary between 1 and 5. Hungr et al. (1984) reported that  $k$  may vary