The experimental study on the geometric similarity of debris flow deposition

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ABSTRACT

With the rapid development of the Chinese economy, many important building projects are planned on debris fans. Because of their location, these new constructions will be threatened by debris flows. Thus, it is important to study debris flow deposition in different conditions. Twenty debris fans under different experimental conditions are considered in order to examine the geometric similarity of debris flow deposition. The experimental results show that the cross-section, profile, and plane configuration of debris fans all have parabolic distributions. The quadratic term coefficients (a1, a2) of the debris fan cross-section and profile define the average deposition slope in the longitudinal and transverse directions. For the plane configuration, -b/2a3 is the degree of deviation of the maximum downstream deposition width and c3 is the ratio of the deposition width at the outlet to the maximum deposition width.

Key words: geometric similarity, debris flow, deposition, laboratory experiments

INTRODUCTION

Debris flow is a sudden natural phenomenon, common in mountainous areas. Debris flows primarily cause erosion and deposition, particularly in the area of the debris fan. With the rapid development of the Chinese economy, many important transportation routes, water conservation and hydropower plants, towns, and factories have been built in, or are planned for, mountainous areas. Many of these projects have been or will be built on debris fans and thus will be threatened by debris flows. Therefore, the study of the geometric parameters of debris fan deposition is essential for organizing and implementing debris flow disaster prevention and mitigation plans.

To date, debris fan deposition prediction studies have mainly involved predicting debris flow volume (e.g., Ikeya, 1980; Tang, 1993; Franz, 2001; Liu, 2002), deposition length (e.g., Perla et alii, 1980; Cannon, 1989; Benda & Cundy, 1990; Zimmermann, 1991; Whipple, 1992; Pierson, 1995; Bathurst, 1997; Iverson, 1998; Villar, 2000; Fannin & Wise, 2001; Lancaster, 2003; Toyos, 2006), and alluvial area (Bull, 1964; Christine & Robert, 2003; Berti and Simoni, 2007). These studies have focused on making two dimensional predictions of debris flow deposition and lack a prediction of deposition depth. In order to make predictions in three dimensions, we must first consider the geometric parameters of debris flow deposition (Xie & Cai, 1998). Xie and Cai (1998) analyzed 72 debris deposition fans formed under different conditions and concluded that the non-dimensional longitudinal and cross-sectional profiles of debris flow fans can be described with Gaussian functions. In contrast, the non-dimensional plan form of debris flow fans can be described with a circular arc. However, the experimental fluid types employed were representative of stony and low viscosity debris flows. The geometric parameters of the viscous debris
flows that typically occur in southwestern China are still unknown. For this paper, a laboratory experiment is designed in order to analyze the geometric parameters of viscous debris flow deposition.

LABORATORY EXPERIMENT

EXPERIMENTAL APPARATUS AND MATERIAL

The experimental apparatus includes a hopper, flume, accumulation plate, and material recycling pool (Figure 1). The hopper measures 50 × 40 × 85 cm, with a capacity of 0.1 m³. The flume is a steel-truss structure with inside measurements of 20 × 30 cm, a valid flow length of 300 cm, and glass-reinforced sides to facilitate observation. The adjustable slope of the flume ranges from 0-20°. The accumulation plate is a rectangular steel-truss structure measuring 300 × 180 cm. A leveling board on the surface of the structure serves as an accumulation plane. The material recycling pool, a brick-molded rectangular pool, is positioned at the end of the accumulation plate. The pool measures 200 × 80 × 15 cm. The materials are cleaned after each experiment for reuse in the following experiment.

The experimental materials come from a sample of the original debris flow collected from the Jiangjia Gully, Dongchuan debris flow observation research station in Yunnan Province, China. The maximum grain size is 10 mm, the median grain size is 1.0 mm, and the average grain size is 3.25 mm (Figure 2).

SETTING

Twenty experiments in three groups, varying the scale and bulk density of the debris flow, and the slope of the accumulation area are conducted (Table 1).

PARAMETERS

The parameters of the debris flow are defined based on the results of experiment No.A3 in Table 1 (Figures 3 and 5).

The X-axis is the cross-section direction, the Y axis is the profile direction, and the Z axis expresses deposition depth. Lc is the deposition length of the medial axis direction. Since the experimental deposition conditions are homogeneous and symmetrical,
a unary quadratic curve symmetrical around the $Z/Z_c$ axis. The vertex coordinate is (0,1).

Thus, $b_1 = 0$, $c_1 = 1$ in formula (1). The shape of the cross-section can be expressed as:

$$Z / Z_c = a_1 \left( X / B \right)^2 + 1$$

Next, we considered the relationship between quadratic coefficient $a_1$ and debris fan deposition. Here, experimental group C in Table 1 as an example is used. The relationships between $|a_1|$, the transversal average deposition slope ($\lambda$), and the slope of the accumulation area ($\theta_d$) are shown in Figure 7.

Figure 7 shows that $|a_1|$ and $\lambda$ have a negative, linear correlation with $\theta_d$. As the accumulation slope increases, the maximum deposition width and depth decrease. Thus, the average crosssection deposition slope decreases as a result. Therefore, the quadratic coefficient, $a_1$, reflects the change in the transverse average deposition slope of the debris fan. The greater the absolute value, the greater the transverse average deposition slope.

**RESULTS AND DISCUSSION**

**GEOMETRIC SIMILARITY OF THE CROSS-SECTION**

The relation between the dimensionless parameters $Z/Z_c$ and $X/B$ are shown in Figure 6.

Figure 6 shows that the cross-section of the debris fan under different conditions has a geometric similarity according to parabolic distribution. This can be expressed as follows:

$$Z / Z_c = a_1 \left( X / B \right)^2 + b_1 \left( X / B \right) + c_1$$

Since the debris fans in terms of a level and symmetrical deposition area are only considered in the experiments, Figure 6 indicates that the cross-section is

$$Z / Z_0 = a_2 \left( Y / L_c \right)^2 + b_2 \left( Y / L_c \right) + c_2$$

$L_c$ is the maximum deposition length. $B$ is the width of arbitrary cross section, $B_{max}$ is the maximum deposition width. $Z_c$ is the deposition depth of the center line of the cross section, $Z_o$ is the deposition depth of the midpoint of the flume outlet. In order to analyze the average deposition slope of the debris fan in the cross section and profile, $\lambda$ is the transversal average deposition slope in the direction of the maximum deposition width (cross-section average deposition slope for short), $\gamma$ is the average profile deposition slope in the direction of the maximum deposition length (average profile deposition slope for short), and $\theta_d$ is the slope of the accumulation area.
can be expressed as:

\[ \frac{B}{B_{\text{max}}} = \frac{a_3}{a_3} \left( \frac{Y}{L_c} \right)^2 + \frac{b_3}{a_3} \left( \frac{Y}{L_c} \right) + \frac{c_3}{a_3} \]  (5)

In the above formulas, \(-b_3/2a_3\) is the axis symmetry and \(c_3\) is the intercept of the curve. The relationship between \(-b_3/2a_3\), \(c_3\) and \(\theta_d\) is shown in Figure 11.

Figure 11 indicates that as the accumulation slope increases, the position of the maximum width deviates further from the outlet. In summary, \(-b_3/2a_3\) is the maximum degree of deviation of the downstream deposition width. The greater the value, the greater the deviation. \(c_3\) is the ratio of the deposition width at the outlet of the gully to the maximum width. The greater the value, the more similar is the deposition width at the outlet of the gully to the maximum width.

**CONCLUSIONS**

In this paper, twenty debris fans under different experimental conditions are examined in order to define the geometric similarity of viscous debris flow deposition. The results indicate that the crosssection, profile, and plane configuration of debris fans all have parabolic distributions. In addition, the physical meanings of the geometric similarity coefficients related to the geometry of debris fan crosssections, profiles, and plane configurations are discussed.
The quadratic term coefficients $(a_1, a_3)$ of the cross-section and profile define the average deposition slope of the debris fan in the longitudinal and transverse directions. The greater the value, the smaller the slope. For the plane configuration, $-b_3/2a_3$ is the degree of deviation of the maximum deposition width. The greater the value, the greater the deviation. $c_3$ is the ratio of the deposition width at the outlet to the maximum deposition width. The greater the value is, the more similar is the maximum deposition width and the deposition width at the outlet.

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