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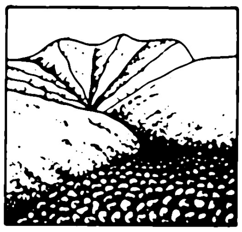
Пятигорск, Россия, 22-29 сентября 2008 г.



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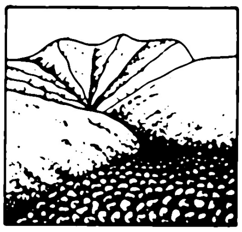

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При создании логотипа конференции использован рисунок из книги С.М. Флейшмана «Селевые потоки» (Москва: Географгиз, 1951, с. 51).
Conference logo is based on a figure from S.M. Fleishman's book on Debris Flows (Moscow: Geografgiz, 1951, p. 51).

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Study on the sensitivity of parameters relating to debris flow spread

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Исследование чувствительности параметров, связанных с распространением селевого потока

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Численная программа, разработанная для полевого применения (Liu and Huang, 2006), используется как основа для анализа в данной статье. Программа использует обобщенную реологическую модель (Julien and Lan, 1991) для моделирования селевых потоков. Рассматриваемые параметры, связанные с распространением селевого потока, включают начальный объем селевого потока, пределы текучести и средний уклон селевого очага. Установлено, что для идеального случая самым чувствительным параметром является начальный объем селевого потока. Распределение очаговой зоны влияет на итоговое распространение селя, но распределение между очагами должно быть на один порядок больше, чем масштаб длины очага.

A numerical program developed for field application (Liu and Huang, 2006) is used as the base for analysis in the paper. The program uses the generalized Julien and Lan (1991) rheological model to simulate debris flows. The parameters considered relating to debris flow spreading include initial volume amounts of debris flow, yield stress and average slope of initiation area. For the lab case, the most sensitive parameter is found to be the initial volume amounts of debris flow. The distribution of the source does affect the final spreading, but the spreading between sources must be one order larger than the source length scale.

1 Introduction

Debris flows are frequent phenomena in Taiwan. In order to minimize the possible hazard caused by debris flows, the normal countermeasures are constructing dams, land use limitation or habitant evacuation. One of the common uncertainties during planning any countermeasures is the hazard zone area and the path of debris flows. There are many empirical formulas that one can use to obtain part of the information needed in the designing processes. Nevertheless, empirical formulas can be very inaccurate on complicated geographic region even in the order of magnitude sense. A better way to obtain information needed is to use numerical simulation.

Although numerical simulation is considered a better approach, the challenges for real engineering projects lie on the uncertainties of many input data. The geographical data is available but never in high precision. The total amount of available soil that can be eroded or mobilized during heavy rainfall and the rheological properties that can correctly represent the field material are also two major problems. Strictly speaking, if these parameters are not precisely resolved, any modelling would be incorrect. However, for engineering purpose, a 20% error in these data may be common; we must understand what the errors that will be induced are in the final result. If the parameters are sensitive, then efforts to find the parameter precisely should be emphasized. On the other hand, for insensitive parameters, a rough estimate should satisfy engineering purpose.

In this paper, Debris_2D model (Liu & Huang, 2006) is used to identify the sensitivity of several parameters relating to the final spreading of debris flows. These parameters include total volume of debris flow, the yield stress and average slope of initiation area. Therefore, these results are very useful for engineering designs and estimate for their effectiveness.

2 Constitute equations

The constitutive relation proposed by Julien and Lan (1991) is used here. The original 1-D version was extended to 3-D by Huang (2003) as following:

$$\tau_{ij} = \tau_0 + \mu_d \varepsilon_{ij} + \mu_c \varepsilon_{ij} \varepsilon_{ij} \quad \left|\tau_{ij}\right| > \tau_0 \ ; \qquad \varepsilon_{ij} = 0 \quad \left|\tau_{ij}\right| \le \tau_0 \tag{1}$$

where τ_{ij} is the stress tensor and ε_{ij} is the strain rate tensor, τ_o is the yield stress, μd is the dynamic viscosity and μ_c is turbulent-dispersive parameter. μ_c accounts for the dispersive stress effect in granular flows. τ_{ij} and ε_{ij} represent the second invariant of the stress and strain rate tensor, respectively. Intuitively, this model, which includes the viscous effect and collision effect, could be used for mudflows and granular flow.

3 Governing equations

From Liu and Huang (1996, 2003, 2006), the leading order approximation can neglect the boundary layer and the governing equations for debris flow in dimensionless variables are

$$\frac{\partial H}{\partial t} + \frac{\partial (uH)}{\partial x} + \frac{\partial (vH)}{\partial y} = 0 \tag{2}$$

$$\frac{\partial (uH)}{\partial t} + \frac{\partial (u^2 H)}{\partial x} + \frac{\partial (uvH)}{\partial y} = -\beta H \frac{\partial H}{\partial x} + GH - \alpha \frac{u}{\sqrt{u^2 + v^2}} \tag{3}$$

$$\frac{\partial (vH)}{\partial t} + \frac{\partial (uvH)}{\partial x} + \frac{\partial (v^2 H)}{\partial y} = -\beta H \frac{\partial H}{\partial y} - \alpha \frac{u}{\sqrt{u^2 + v^2}} \tag{4}$$

where u, v are dimensionless velocity components in x, y directions, respectively. H is dimensionless depth of plug flow. Expressing characteristic depth, wave length and velocity of debris flow by D, L and U. The normalized parameters are

$$\beta = gD\cos\theta / U^2 \ , \ G = gL\sin\theta / U^2 \ , \ \alpha = \tau_o L / \rho U^2 D \tag{5}$$

They represent the effect from pressure gradient, gravity and yield stress, respectively. Equations (2), (3) and (4) can be used to solve the three unknowns H, u and v.

If debris flow starts from a stationary pile of mass, it can flow only if gravity effect and pressure gradient overcome the bottom yield stress. Therefore, the starting condition can be obtained by setting all velocities zero in (3) and (4) to reach

$$\left(\frac{\partial H}{\partial x} - \frac{G}{\beta}\right)^2 + \left(\frac{\partial H}{\partial y}\right)^2 \ge \left(\frac{\alpha}{\beta H}\right)^2 \tag{6}$$

4 Numerical scheme and verification

To compute H, u and v from equation (2), (3) and (4), we use Adams-Bathforth 3rd order scheme in time and central difference and 1st order upwind scheme in space. Upwind method is used for convective terms. Central difference is used for all other terms. The Debris_2D model had been verified by 1-D and 2-D analytic solutions (Liu, Huang, 1996), and several field case (Huang, 2003) (Liu and Huang, 2006). All tests give very good results.

5 Sensitivity analysis

In an engineering project, the final influence area is a very important consideration for any mitigation methods. The design of a countermeasure also depends on the velocity and depth of debris flows. There are many input data needed for a real case simulation, any error in the input data will induce error in the final outcome. However, it is very difficult to obtain accurate input data from the field. If a 20% error in the input data will only induce 1% error in the final result, then this input data is not sensitive and rough estimate may suffice. On the contrary, if a 1% error in the input data will induce 10% error in the final result; this data is very sensitive and have to be dealt carefully.

The most important input data are the material properties such as the yield stress, the source volume distribution as well as the average slope of topography.

To vary the three dimensionless parameters, we change the physical inputs so that one can appreciate the physical importance. The scales under flume environment are 1m length scale, 0.5m width scale, 0.5m depth scale, 1m/sec velocity scale, and 1600kg/m^3 for density ρ. The standard case runs for τ_o =100 Pa, 0.225 m^3 total volume, and θ=15°. The results for snap shots at time equals 0, 20, 40, 60 and 80 sec are plotted in Fig. 1.

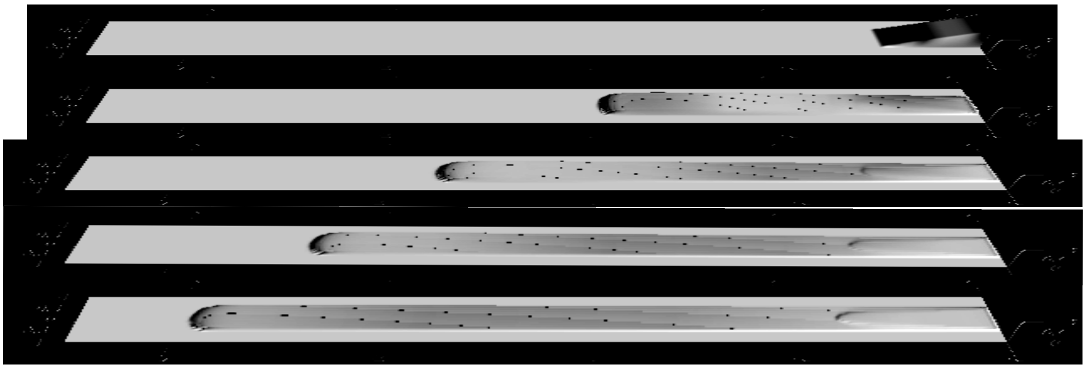

Fig. 1. The propagation of debris flow for the Standard case τ_o =100 Pa, 0.225 m^3 total volume, and θ=15° . The front shock is clearly shown. That is the location for maximum depth.

The corresponding maximum depth variation and front position change are plotted in Fig. 2a and 2b.

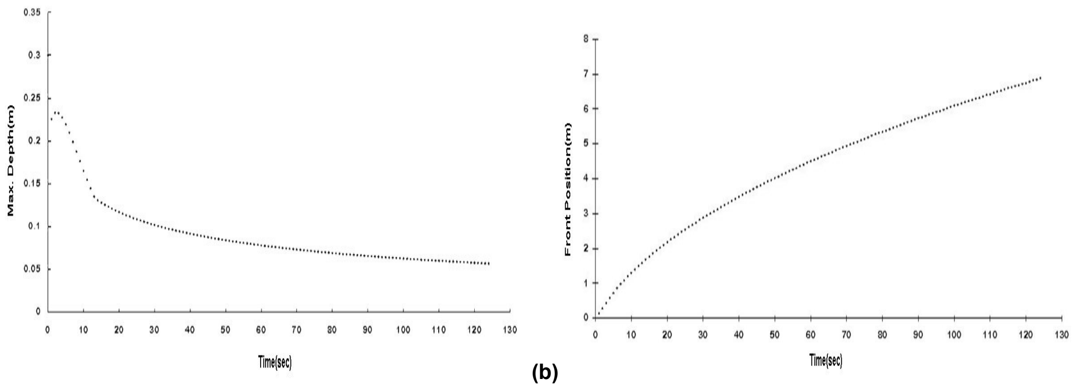

Fig. 2 The temporal variations of maximum depth (a) and front position (b). The front depth first increases due to weak shock. Then the depth decreases as flow travels downstream. This is common for debris flows. The final front position is around 7m.

Then we vary all three parameters as listed in Table 1. Each parameter is varied within 20% with respect to the standard value, so that we can see the effect of each parameter.

Table 1. Range of parameters tested.

G: -10% ~ 10%	Average Slope θ=5°	G: 1.541~1.883
Volume: -10% ~ 10%	*Volume* = 0.075 m^3	Volume: 0.0675~0.0825
α: -10% ~ 10%	Yield stress τo =110 Pa	α: 0.18750 ~0. 22917

A sample result is plotted in Fig. 3.

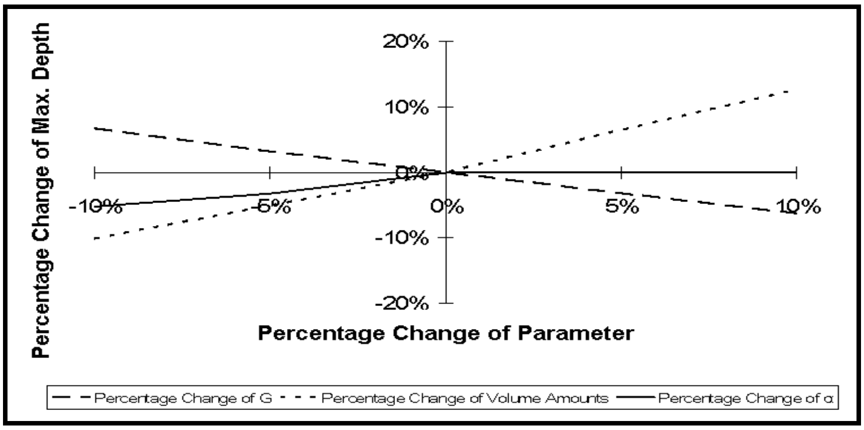

Fig 3. Horizontal axis is the percentage change of different parameters and the vertical axis the corresponding change of the simulated results. Increasing average slope (G: long dash line) and initial volume (short dash line) increase the final travel distance of the front while increasing the yield stress (α: solid line) decreases the distance. The effect of initial volume and average slope is about the same. The effect of yield stress is not as important.

6 Results and discussion

The three parameters slope, volume and yield stress represent different mechanisms. Slope implies work done by gravity. Therefore, larger slope implies flow will last longer and. Yield stress actually is the internal friction of material, it is an energy damper. Larger yield stress will consume more energy. Therefore, debris flows can not flow fast and long for larger yield stress. Initial volume represents the initial potential energy.

One of the results implied is that yield stress is never the dominant parameter. Slope effect and volume effect is almost the same but the significance of slope decreases as slope becomes less than 5°. This agrees with the common belief that debris flow starts to decelerate for slope of 5° or less.

7 Conclusion

We use the Debris_2D model (Liu and Huang, 2006) to find sensitive of the some spread characteristics and source properties of debris. The simulate results shows that the most sensitive parameter is the initial volume amount. Therefore, the distribution of the source does affect the final spreading, but the spacing between sources must be of the order of the watershed to induce meaningful difference. The next sensitive parameter is the average slope. But digital elevation data seldom induce large error in slopes.

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