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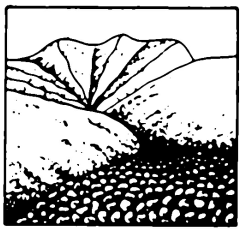

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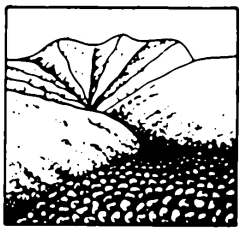

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При создании логотипа конференции использован рисунок из книги С.М. Флейшмана «Селевые потоки» (Москва: Географгиз, 1951, с. 51).
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Numerical simulation of debris flow movement and its application in debris flow risk zoning

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Численное моделирование движения селей и его приложение для зонирования селевого риска

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Зонирование риска селей эффективно для оценки уровня риска для уязвимых районов и имеет важное значение для землепользования, проектирования дорог и т.п. в горных районах. Метод зонирования риска основан на численном моделировании, которое становится основным направлением исследований. В данной статье обсуждается метод численного моделирования селей, основанный на частичной модели. Моделирование движения селя дает значения двух параметров – скорости и глубины селевого потока - важных для зонирования риска. Два метода классификации зонирования зависят от хода моделирования. Первый – классификация зон риска в зависимости от распределения максимума кинетической энергии, второй – согласно пределу устойчивости для зданий к давлению под воздействием селя.

Risk zoning of debris flows is effective for assessing risk levels in vulnerable areas and is important in guiding land-use layout, design of highways and railways etc. in mountain areas. The method of risk zoning based on the numerical simulation is our main research direction. In this paper, the method for numerical simulation of debris flows based on the particle model is discussed. The numerical simulation of debris flow movement can give two important parameters, velocity and depth of debris flow, for risk zoning. Two methods of classification of debris flow risk zoning, depending on the numerical simulation were carried out. One is classifying the risk zoning according to the distribution of the maximum kinetic energy, and the other one according to ultimate bearing pressure of buildings under impact.

1 Introduction

Risk zoning of debris flow is effective on assessing the risk degrees in the dangerous area of debris flow and has important significance to guide land-use layout, design of highway and railway, etc. in mountain areas. There are many classification methods of risk zoning, but most of them are based on the background elements of debris flow valleys. But some limitations have been observed in these methods in the sense that the result of classification excessively depends on the experts' specialty background and their work experience. Along with the development of debris flow kinematic model and its numerical simulation, the method of risk zoning based on numerical simulation has been becoming the main study direction. The numerical simulation of debris flow movement can give debris flow velocity and depth. Both of them are the most important parameters for the risk zoning.

A method of debris flow numerical simulation of debris flow based on the particle model was discussed in this paper. Using the result of numerical simulation, the methods of classification of the risk zoning based on the distribution of the maximum kinetic energy and based on the ultimate bearing pressure of building under impacting were carried out.

2 Method of numerical simulation of debris flow movement

The harmful area of debris flow is mainly the alluvial fan. In the fan, there are often some obvious grooves or man-made channels. There is no fixed boundary to limit the debris flow movement on the flat fan, but the movement in the channel is limited in a fixed boundary. So the movements are different in the two situations, which makes necessary to simulate debris flow by different methods.

2.1 Numerical simulation of debris flow movement on the fan area

On the fan with wide surface relief and gentle slope, the debris flows diffuse freely as an inundant flow. Because the depth of the debris flow is far less than the length and the width of the fan, the vertical velocity of the debris flow can be ignored, and the debris flow can be simplified as a kind of movement on a two-dimensional plane. Moreover, supposing that the material of debris flow is homogeneous and incompressible, then the momentum equation of debris flow can be written as:

$$\begin{aligned} \frac{Du}{Dt} &= gS_{sx} - gS_{fx} \\ \frac{Dv}{Dt} &= gS_{sy} - gS_{fy} \end{aligned} \tag{1}$$

where u and v are the components of average velocity in x- and y-direction, g is the gravitational acceleration, S_{sx} and S_{sy} are bed slopes, S_{fx} and S_{fy} are frictional slopes respectively in x- and y-direction of the fan.

In Eq. 1, S_{sx} and S_{sy} reflect the effect of gravity while the friction slopes can be considered to include four parts: yield stress, viscous stress, dispersive stress and turbulent stress. According to the expression of O'Brien et al, the frictional slope can be given by:

$$\begin{aligned} S_{fx} &= \frac{\tau_B}{\gamma_m h}\operatorname{sgn}(u) + \frac{2\mu_B u}{\gamma_m h^2} + \frac{k_c u\sqrt{u^2+v^2}}{gh} \\ S_{fy} &= \frac{\tau_B}{\gamma_m h}\operatorname{sgn}(v) + \frac{2\mu_B v}{\gamma_m h^2} + \frac{k_c v\sqrt{u^2+v^2}}{gh} \end{aligned} \tag{2}$$

where τ_B is the yield stress, γ_m is the bulk density, h is the depth, μ_B is the coefficient of rigidity, k_c is the coefficient of friction that equals to B/C^2 (C is the Chézy coefficient), sgn $(\cdot)$ is sign function. It follows from the expression of frictional slope that when the depth is less than one certain value, the resistance of the movement is larger than the component of gravity along the slope surface. And the debris flow will gradually slow down and deposit.

Wang, et al (1997), based on two-phase flow theory and Lagrangian-Euler numerical method, presented a particle model for alluvial fan formation. The continuity equation was implied in the arithmetic in the model. Debris flow is considered as the aggregation of a great deal of small grains, and calculated the velocity and the location of every grain in each time step based on the discrete momentum equation. This model is employed to simulate the movement of debris flow in the fan.

2.2 Numerical simulation of debris flow movement in the channel

When debris flows move in the fan with deep and narrow grooves, it can be disposed as one dimension flow. Because the grade of the sidewall of the groove is extremely big, two-dimensional model can not be applied to this situation. Ignoring the velocity in side direction and choosing average velocity on the cross-section, then the continuity equation and momentum equation along the flow direction are as follows:

$$\frac{\partial h}{\partial t}+\frac{\partial Uh}{\partial x}=0 \tag{3}$$
$$\frac{\partial U}{\partial t}+\frac{\partial}{\partial x}(\beta U^2+gh)=gS_s-gS_f$$

where h is the flow depth, U *is* the average velocity on the cross-section, β is the coefficient of correction of momentum and S_s is the bed slope. The frictional slope can be written as

$$S_f=\frac{\tau_B}{\gamma_m h}+\frac{2\mu_m U}{\gamma_m h^2}+\frac{k_c U^2}{gh} \tag{4}$$

3 Method of classification of risk zoning based on the distribution of kinetic energy

The risk of debris flow means the destructive ability of destruction which is embodied mainly by the wallop. In the numerical simulation, the flooded area is divided into many grids with equal area, and fluid in each grid is considered as a grain in motion. For each grain, there is an expression $F=m\Delta V/\Delta t$. If time of action of fluid on obstacle is equal for each grid, wallop (F) is only related to momentum of the grain (mv).

$$Z = mv = ah\rho v \tag{5}$$

where a is the area of the grid, h is the depth of slurry, ρ is the density of the fluid, and v is velocity of the fluid. Because the area of the grid is the same, Z is a function of density, depth, and velocity of debris flow. For a specific event, however, ρ is often a constant, then the product a ρ can be replaced by a coefficient K:

$$Z = K\,h\,v \tag{6}$$

Eq.6 is the main model for the risk zoning of debris flows. Z is the destroying ability for each grid, namely the risk of debris flow. Based on its distributing character, Z can be divided into several intervals corresponding to different risk zones in the inundation area.The intervals can be determined by probabilistic method. The equal-variance method is employed to determine the intervals as Eq. 7.

$$S(Z)+(i-1)\times V(Z)<Z<S(Z)+i\times V(Z) \tag{7}$$

where $S(Z)$ is the mean of Z, $V(Z)$ is the variance of Z and i rounds numbers. When i=1, if the value of Z is located in the interval of [$S(R)$□$S(R)+V(R)$], the risk is medium degree, if it is more than $S(R)+V(R)$, the risk is high degree, and if it is less than $S(R)$, the risk is low degree. If it is necessary to make more detail risk zoning, the value of i can be sampled larger.

4 Method of classification of risk zoning based on the ultimate bearing pressure of building under impacting

The major objects harmed by debris flows are the buildings set up on the fans, and the major manner of destructing buildings is impact failure. Assuming the velocity of every grain becomes zero after it strike on a building, the momentum variation of every micelle is:

$$dM=\beta\rho dtvQ \tag{8}$$

where, dM is the momentum of every micelle (kg•m/s), h is the depth of micelle(m), ρ is the density of debris flow(kg/m^3), υ is the velocity of debris flow(m/s), Q is discharge of debris flow(m^3/s), β is the coefficient of correction and dt is time slice(s) . If Fdt is given as the impulse of the micelle from all external forces in dt, Eq.1 can be rewritten as:

$$\beta\rho Qv=F \tag{9}$$

Substituting $Q=ahv$, it gives

$$\beta\rho ahv^2=F \tag{10}$$

F is the external forces bore by the grain while the gain strike the building and its velocity becomes zero, simultaneously, the external forces bore by the building is equal magnitude with opposite direction. If the ultimate bearing pressures of different structures buildings can be tested through impact failure experiment, the ultimate bearing pressures will be the index of debris flow risk zoning. Setting up δ (N/m^2) as the ultimate bearing pressure of the building, Eq. 10 can be overwrote as $\beta\rho ahv^2=\delta ah$, namely,

$$\beta\rho v^2 = \delta \tag{11}$$

At present, there are two main building structures in Chinese mountain towns, middle and low-layer reinforced concrete frame structure and multilayer brickwork mixed concrete structure. The impact failure experiment for both structures had been done in the laboratory. According to the experiment, the ultimate bearing pressure of building with reinforced concrete frame structure is 110.56 KN/m^2, and that of building with brick-concrete structure is 18.22 KN/m^2. Based on this result of impact failure test, three grade zones can be given with the key demarcation points as Table 1.

Table 1. The momentum index classification of debris flow risk zoning.

Risk zones of debris flow	Classification intervals (KN/m^2)
High risk zone	$\beta\rho v^2 \geq 110.56$
Medium risk zone	$18.22 \leq \beta\rho v^2 < 110.56$
Low risk zone	$\beta\rho v^2 < 18.22$

5 Conclusion

The numerical simulation of debris flow movement is a good tool for debris flow risk zoning for the velocity and depth of debris flow can be given by it. Because the movements of debris flow on the fan with general slope and in the channel are different, the former can be simulated by the two-dimensional model and the later can be simulated by one-dimensional model. The result of numerical simulation of debris flow movement can be applied in the risk zoning of debris flow with two ways. The first one is classifying the risk zones based on the distribution of momentum of debris flows calculated by the velocity and depth. The second one is classifying the risk zones based on the distribution of impact force of debris flow calculated from the simulation result. The classification intervals were determined by the test of ultimate bearing pressures of buildings with different structures under impacting.

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