Application of Extended DDA to Landslide Risk Analysis

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1. Introduction

Slope instability occurs in many parts of urban and rural Japan. This not only often impacts on housing, roads, railways and other development but also leads to injury/loss of life. The term landslide here denotes “The movement of a mass of rock, debris or earth down a slope. When assessing the potential dangerous degree of a slope, it is not only necessary to estimate its stability but also to estimate its resulting anticipated damage. For this purpose, the quantitative risk analysis is very important and useful, which is defined as the integration of the frequency and the consequences.

Frequency analysis is estimating the probability of landslide occurrence. Consequence analysis is estimating property damage and injury/loss of life as well as the other effects on the public and politics. When assessing landslide risk, it is important to be able to estimate the distance the slide mass will travel and its velocity. These factors determine the extent to which the landslide will affect property and persons downslope, and the ability of persons to take evasive action. The travel distance depends on (1) slope characteristics; (2) mechanism of failure; (3) type of movement; (4) characteristics of the downhill path. Up to now, statistical and empirical methods have mainly been used in risk analysis. However, no method among them can consider all of above aspects in its estimation of the travel distance.

For this reason, we present a way of risk estimation using extended Discontinuous Deformation Analysis (DDA) in this paper. The travel distance and velocity can be investigated in detail under the consideration of above four aspects by DDA simulation of a landslide.

2. Landslide Risk Analysis

Risk analysis consists of three steps: scope definition, hazard identification and risk estimation. Risk estimation includes frequency analysis and consequence analysis. Up to now, for frequency analysis, there are following methods available to estimate the probability of landslide: (1) Assessment of the historic record of landslide; (2) Empirical methods based on slope instability ranking system; (3) Relationship to geomorphology and geology; (4) Relating the historic record of landslide to rainfall intensity and duration and frequency; (5) Newmark’s stability formula for earthquake induced landslide. Consequence analysis is to estimate property damage and injury/loss of life, which is mainly based on the estimation of the travel distance and velocity of landslide. Several empirical formulas have been presented but they are different from place to place. For example, Schiedegger’s empirical formula is often used:

$$\log(H / L) = -0.157 \log V + 0.624 \qquad (1)$$

where, L is the travel distance, H is the slope height and V is the volume of collapsed debris. It is obvious that the travel distance is not only related to H and V. Therefore, we propose to apply DDA to risk estimation.

3. The Extended DDA and Its Application to the Simulation of Landslide

Discontinuous Deformation Analysis (DDA) was developed by Shi in 1984. It is an effective numerical method and can be applied for both strain-stress analysis of large deformation problems and simulation of rock mass movement. By the application of the DDA, the slope stable factor can be calculated for slopes under the driving forces from earthquake or rainfall, that is, the frequency of landslide can be estimated. And the rock motions after failure can also be simulated.

In order to simulate landslide more reliably and efficiently, we have improved and extended the original DDA on the following aspects.

(1) Solve the problem of block expansions due to rigid body rotation error. There is a phenomenon in the simulation of rock fall by the original DDA that the volume of a falling stone usually gets expansive if it moves with large rotation. By close examinations, it is found that the phenomenon of block area expansion is caused by rigid body rotation error in displacement function. This problem has been solved in the extended DDA.

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can be good enough in agreement with those from experiments in situ.

(3) Consider energy loss. The calculated bouncing height by the original DDA is generally larger than that from experiment when a stone is bounced from the slope. There is energy loss after a stone collided against the slope because some motion energy was transfer to heat and sound energy and some was absorbed by plastic deformation of the soft layer on the slope surface. The energy loss due to collision can be simulated in the extended DDA.

By using the extended DDA, the motion behavior of falling stones, such as the falling paths, velocities, jump heights and distances, and impact force between falling stones and constructions, can be investigated in detail (Fig. 1), which is also very much useful in the design of the protection construction.

Fig. 2 shows an example of landslide calculated by using the extended DDA. It can be seen that the travel distances are different from friction angles between debris and slope surface.

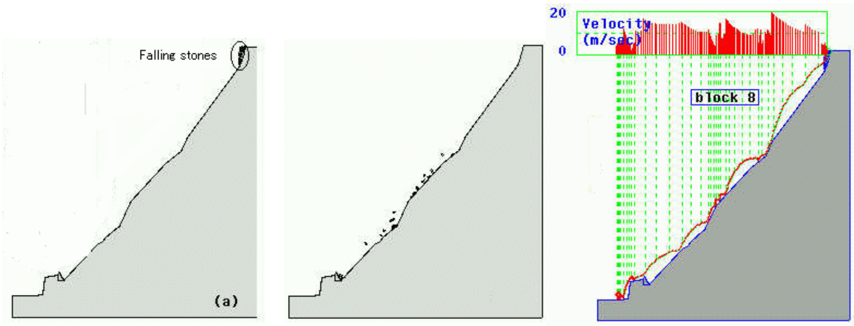

Figure 1 Rock fall simulation by the extended DDA

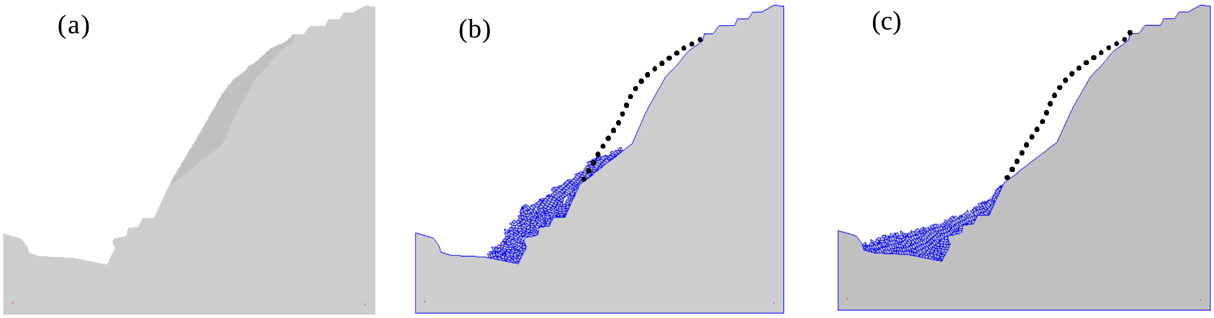

Figure 2. Landslide simulations by using the extended DDA. (a) the slope; (b) the result for friction angle 30^0; (c) the result for friction angle 0^0.

4．Conclusions

The consequence estimation in risk analysis is mainly based on the knowledge of the motion behaviors of landslide. How to estimate distance and velocity is the key point in risk analysis. Also, the knowledge of falling path, jump height and jump distance is very important for the reasonable design of protective structures, which is relative to risk treatment. It has been shown that the extended DDA is a reliable and efficient method for simulating and investigating the motion behaviors of a landslide in detail. This is because the following aspects can be considered in calculating the travel distance by using the extended DDA: (1) Geometrical aspect of a slope such as height, gradient and detail surface shapes; (2) Nature of slope material such as elastic parameters, cohesion and friction; (3) Mechanism of failure such as slide, fall and topple; (4) Type of movement such as sliding, rolling and bouncing; (5) The drag resistance from air and plants; (6) Energy loss for bouncing movement.

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