Simulation of Rockfall Trajectories and Validation of Countermeasure Design Using Distinct Element Method

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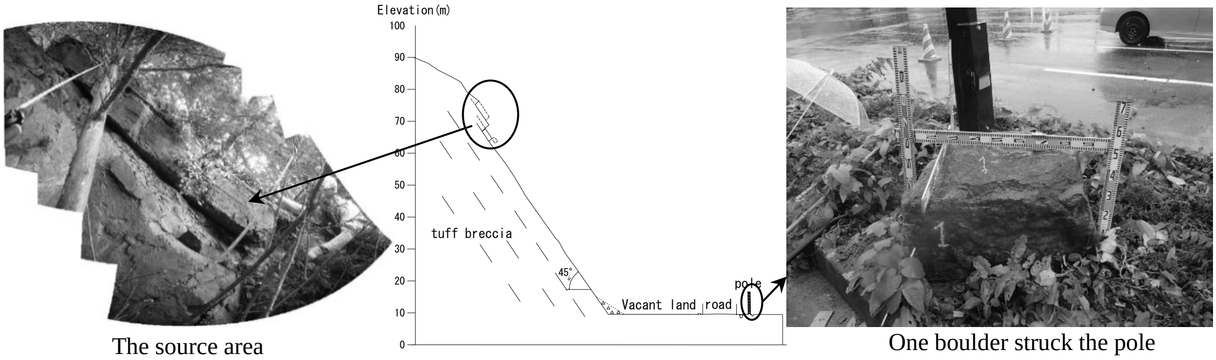
INTRODUCTION

An important issue in the evaluation of potential hazard related to rockfall is the simulation of the traveling distance of the falling blocks, which is necessary to identify the potentially endangered area. This information is also fundamental for the design of appropriate countermeasure works, which are intended to reduce the potential impact of rockfall on the infrastructure, transportation lines and people. The accuracy of rockfall trajectory simulation depends to a large extent on the calculation of the rebound of falling boulders on different parts of a slope where rockfall could occur. Distinct element method (DEM) provides a powerful analytical tool for modeling rockfall behaviors, such as trajectories, velocities and energies of falling rocks. Several input parameters is necessary for DEM simulation, such as normal stiffness, shear stiffness, frictional coefficient and damping coefficient. Among these parameters, the damping coefficient is the key factor for affecting the rockfall behaviors in the DEM simulation. In this paper, a damping coefficient is presented for rockfall simulation using a DEM numerical code UDEC (Itasca 2012). The method is used to simulate the trajectories of an actual rock fall event and reproduce the dynamic process of rolling, rebounding and sliding. Using the parameters which are identified from back analysis of the rockfall event, the validation of the designed earthen embankment as a temporary countermeasure is verified by the simulation.

A rockfall event occurred at a road slope in Japan. The field investigation shows that a large rock mass (estimated 7000 kg) detached from the tuff breccia cliff, and shattered into about 20 disc/rectangular shaped rock blocks which were found at the foot of the slope. A rectangular boulder measuring approximately 0.8 by 0.45 by 0.5m thick, run out beyond the base of the slope, and run across the road, and struck a steel lighting pole before coming to rest (**Fig.1**). Fortunately, there were no injuries and no car damaged. After the rockfall event, the retaining wall was built in order to prevent the potential rockfall boulders from falling onto roadway.



The source area

One boulder struck the pole

Fig. 1 The field situation of a rockfall event

METHODS AND SIMULATION RESULTS

The damping is determined with the parameters of the average frequency (Equ.(1)) and the fraction of critical damping (Eq. (2)) at this frequency.

$$f = \frac{1}{2\pi}\sqrt{kl/m} \qquad (1) \qquad\qquad h = \ln(\frac{1}{R^2}) \qquad (2)$$

where f is the average frequency of rock boulders, l is joint length, k is joint stiffness, m is mass of rock block, h is the critical damping and R is rebound coefficient. All the parameters determined by the back analysis for the rockfall are listed in Table 1.

Based on the field investigation, the rock block can be modeled to six boulders of 1m×1m. **Fig. 2** shows the dynamic propagation of the rockfall event. The rebound of the rock boulders can be controlled by the manipulation of the damping parameters. The simulation results are in good agreement with field investigations.

It is clear that, for the parameters chosen in this study, the designed earthen embankment is sufficient to catch the blocks falling down the slope (**Fig.3**).

Tab. 1 Parameters for rockfall simulation

rock boulder	density(kg/m^3)	2400	rock slope	density(kg/m^3)	2400
	frequency (cycles/s)	282		friction(˚)	40
	damping	2.10	sediments at the base of slope	density(kg/m^3)	1800
joint	normal stiffness (GPa/m)	23.1		friction(˚)	35
	shear stiffness(GPa/m)	7.54	roadway	density(kg/m^3)	2300
	friction(˚)	40		friction(˚)	30

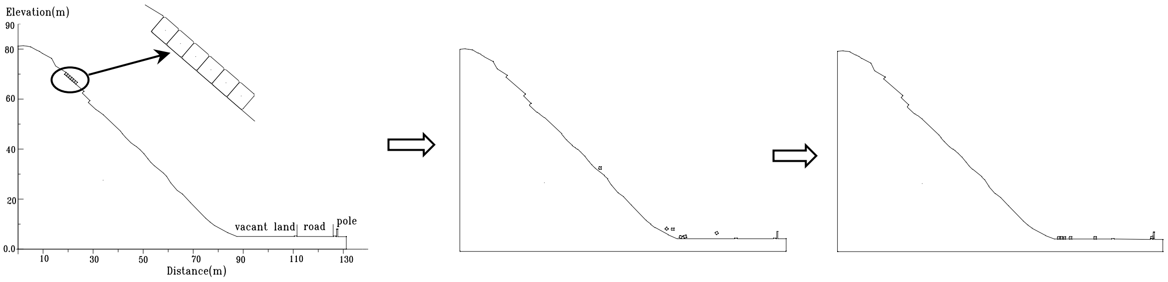


Fig. 2 The simulated dynamic propagation of the rockfall event.

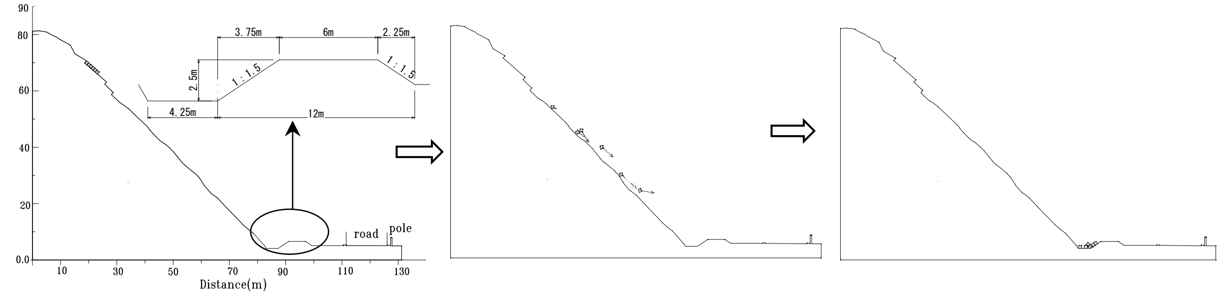


Fig. 3 The validation of the earthen embankment by the rockfall simulation.

CONCLUSIONS

Using the effective damping coefficient presented in this paper, the simulation reproduces the dynamic propagation and movement of a well-documented rockfall event occurred in Japan. The simulation result is in good agreement with field investigations. The validation of the designed earthen embankment is verified by the rockfall simulation.

Keywords: Rockfall, DEM, Simulation, Damping coefficients, Countermeasure