The Effect of Passing Probability at Slope Toe by Material Property Variation for 2D-Rockfall

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1. Introduction

Rockfall makes it difficult for engineers to estimate the fence location for disaster prevention because of its strong randomness. The trajectory of rockfall presents a large variability in reality by the variation of material property, rock shape, and slope topography caused by different natural environments. Therefore, it is necessary to figure out the effect of material property variation on rockfall movements.

2. Rockfall Model

In this study, a database titled "Reality of Cliff Failure Disaster" from TECHNICAL NOTE of National Institute for Land and Infrastructure Management is referred to determine the typical rockfall slope model. The database is a statistical survey of collapse that occurred throughout Japan between 1972 and 2018 by Nakaya et al [1]. A total of 19,035 events are included. Based on this survey, a typical slope model for high-risk rockfall is assumed as shown in Fig. 2. The model has a 50 degree slope of the linear type like shown in Fig. 1, and the slope height is 15 m. A rock represented by a regular sphere with a diameter of 0.5 m is released at the top zone (h/H = 0.8) from a 2 m height with no initial velocity.

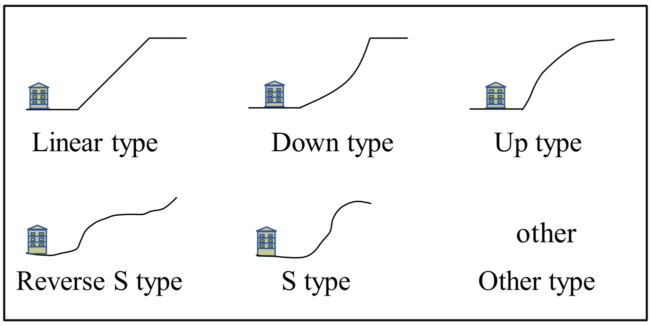

Fig. 1 Six types of slope cross-section shapes in [1].

3. Monte Carlo Simulation (MCS)

MCS is conducted to consider the effect of material property variation by using Distributed Contact Discrete Element Method (DCDEM) [2] on 2D-rockfall movement. Seven rockfall mechanic parameters, Young's modulus, density, kinetic friction coefficient, and coefficient of restitution for rock and slope separately are selected for random input parameters as shown in Table 1. The coefficient of variation, *cov*, is used to represent the variability, calculated as σ/μ, where σ is the standard deviation, and μ is mean. In this study, *cov* is varied in a range of 0.1~0.4.

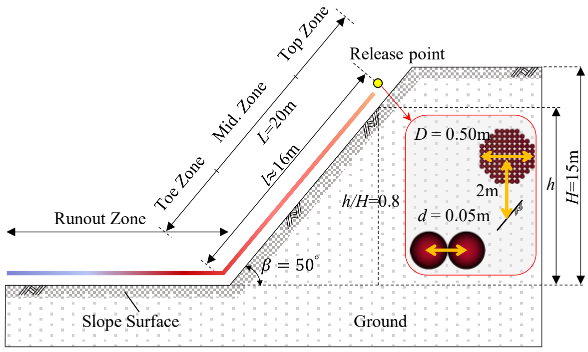

Fig. 2 Rockfall model.

Table 1 Input material properties for 2D-rockfall

Parameter	Mean	*cov*	Distribution
E_{rock}	60 GPa	0.10~0.40	Log-normal
$\mu_{f\,rock}$	0.60	0.10~0.40	Beta
COR_{rock}	0.70	0.10~0.40	Beta
ρ_{rock}	2700 kg/m^3	0.10~0.40	Log-normal
ν_{rock}	0.25	-	-
E_{rock}	3 GPa	0.10~0.40	Log-normal
$\mu_{f\,rock}$	0.70	0.10~0.40	Beta
COR_{rock}	0.30	0.10~0.40	Beta
ν_{rock}	0.35	-	-

cov: coefficient of variation

4. Passing Probability

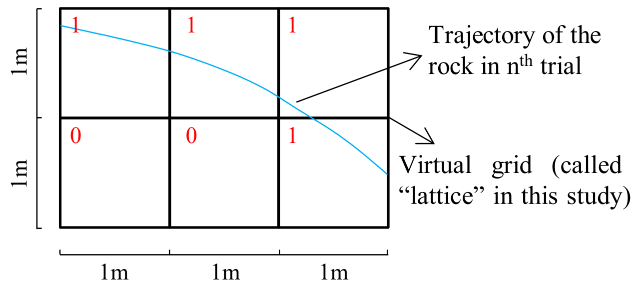

Fig. 4 Lattice for 2D-rockfall

キーワード passing probability, material property variation, Monte Carlo Simulation, 2D-rockfall
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In order to investigate the passing probability of rockfalls, an analysis is carried out as follows. Firstly, the 2D space is divided into 1m*1m virtual lattice in uniform size like shown in Fig. 4. Each lattice passed by the rock in one set of material properties are marked as 1, and those not passed are marked as 0. The same operation is implemented for all sets of the trial. Finally, the lattice at the corresponding position is superimposed to calculate the number of passing rocks. Passing probability, *P,* is represented by the ratio of the number of passing rocks, $N_{passing}$, and the total number of trials, N_{trial}, as follows:

$$P = \frac{N_{passing}}{N_{trial}} \tag{1}$$

5. Results

Fig. 3 illustrates the relationship between the number of MCS, the mean, μ, and the standard deviation, σ, of runout distance with *cov* = 0.10. It can be judged that the variation decreases quickly after 100 iterations, and 2000 times MCS iterations are enough to ensure the convergence of the results.

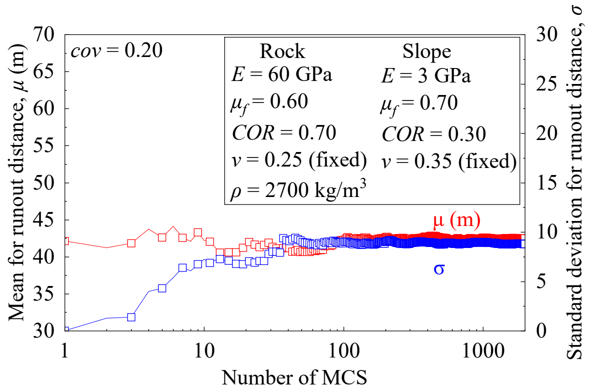

Fig. 3 Mean and SD of runout distance against number of MCS with *cov* = 0.20.

Fig. 5 depicts the passing probability map with the input material property variation *cov* = 0.10~0.40. Black lattice represents the passing probability of rockfalls below 60%, green represents 60~80% and red represents 80~100%. Slope toe is an important location because in Japan lots of fences are installed at the slope toe such as the National route. The slope toe is marked by the pink circle in Fig. 5. The area of the colored grid becomes greater around slope toe, which means that with increasing the input material property variation, the rockfall movement shows a significant variation in jumping around slope toe. When the input material variation *cov* = 0.1, the maximum number of the lattice in the vertical direction around slope toe is 3. The number of that is 4 for *cov* = 0.20, 5 for *cov* = 0.30 and 0.40, respectively. All of them are with a passing probability below 60%. As the material property variation *cov* increases from 0.1 to 0.4, the passing probability below 1m height during the location 15m~20m is decreased because the red lattice is replaced by green lattices gradually. Specifically, the number of green lattices is increased from 1 to 4 for *cov* = 0.10~0.40, which can be observed in the pink circle in Fig. 5.

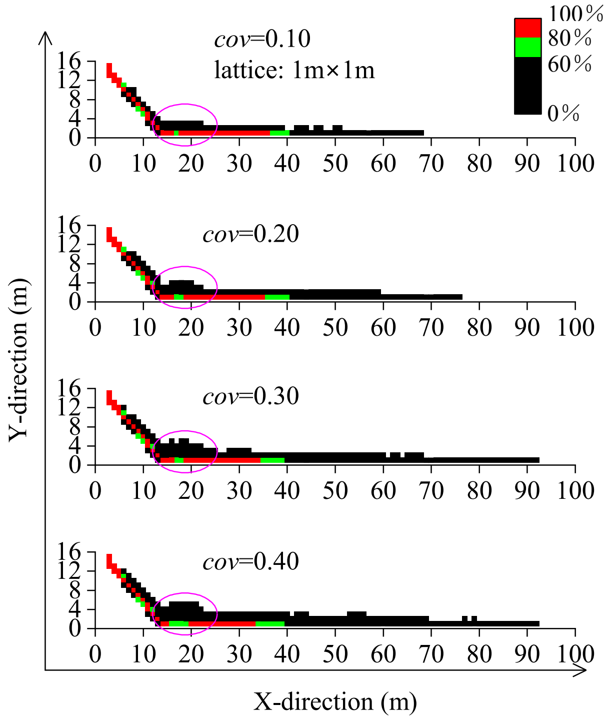

Fig. 5 Passing probability mat with *cov*=0.10~0.40

6. Conclusions

a) As the material property variation *cov* increased from 0.1 to 0.4, the max. jumping height around slope toe is increased by 60%, from 3m to 5m.

b) As the material property variation *cov* increases from 0.1 to 0.4, the passing probability below 1m around the slope toe is decreased from 80~100% to 60~80%.

Reference

[1] Hiroaki, N., Shigetaka, T. and Akito, K.: Reality of cliff failure disaster, TECHNICAL NOTE of National Institute for Land and Infrastructure Management, No. 1122, 2020.

[2] Ricardo B. Canelas et al..: SPH–DCDEM model for arbitrary geometries in free surface solid–fluid flows, Computer Physics Communications, Vol. 202, pp. 131-140, 2016.