The soil runout analysis of slope considering spatial variability

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Introduction

Spatial variability of soil properties is considered as a major source of uncertainties in geotechnical engineering [1]. Effects of spatial variability of soil properties on slope stability have received considerable research attention in the literature. However, it is worth noting that the consequence of a landslide is often determined by the transportation and final deposition of the sliding soil mass, which might also be significantly affected by the spatial variability of soil properties. This study aims to investigate effects of soil property spatial variability on the occurrence and postfailure behavior of soils using Monte Carlo simulation (*MCS*) combined with Material Point Method (MPM).

Analysis model

The slope as shown in Fig. 1 is selected as the research model, where has a length of 130 m and a height of 40 m. The failure process under gravity is simulated and the slope failure is triggered by gradually increasing the strength reduction factors [2]. It is noted that the vertical displacement at the edge of the slope crest is monitored to determine the factor of safety (*Fs*).

Table 1 Input parameters

Parameters		Value
Cohesion, c (kPa)	mean	100
	COV	0.2 and 0.6
Internal friction angle, ϕ (°)	mean	30
	COV	0.1 and 0.3
Correlation length, θ (m)		20 m
Young's modulus, E (MPa)		100
Poisson's ratio, v		0.3
Density, ρ (g/cm^3)		2.0
Monte Carlo iteration		1000
Residual strength, σ_r (kPa)		0.50 σ_{peak}
Softening modulus, M (MPa)		$E/(2(1+v))$

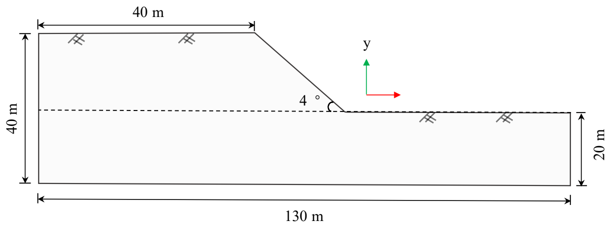

Fig. 1 The analysis model

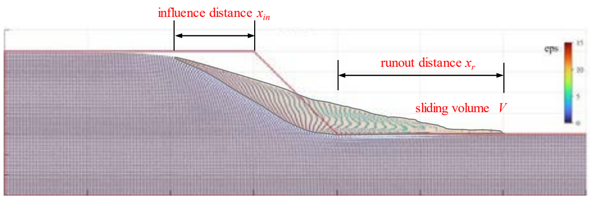

Fig. 2 Features of a postfailure slope

Random field model

The spatial variability of the parameter can be characterized by the distribution and the scale of fluctuation. The soil properties, cohesion c and shear strength tanϕ are modeled in this study as the isotropic random field [3]. The random fields of the shear strength is assigned as log-normal distribution. The scale of fluctuation is defined as the distance within which the values of soil parameters for two points are significantly correlated. Table 1 shows the input parameters.

Analysis results

Because the factors of safety estimated in this study are all larger than 1.0, stability number Ns is used to evaluate the stochastic property of slope stability with the spatial variability of the soil properties. To investigate the postfailure process of sliding mass, as shown in Fig.2, the runout distance x_r, influence distance x_{in} and sliding volume V are featured. The cumulative mean of Ns, x_r, and V in the *MCS* for trial number n = 1000 are plotted in Fig. 3 (a), (b) and (c), respectively. It shows that the variables almost reach a stable value within 1000 trials of the *MCS*. Thus, it is suggested that the 1000 iterations are sufficient to obtain an accurate and reliable evaluation of runout characteristics. It can be seen from the Fig. 3 that the greater the spatial variability is, the smaller the mean stability number is, while the mean runout distance and sliding volume are larger.

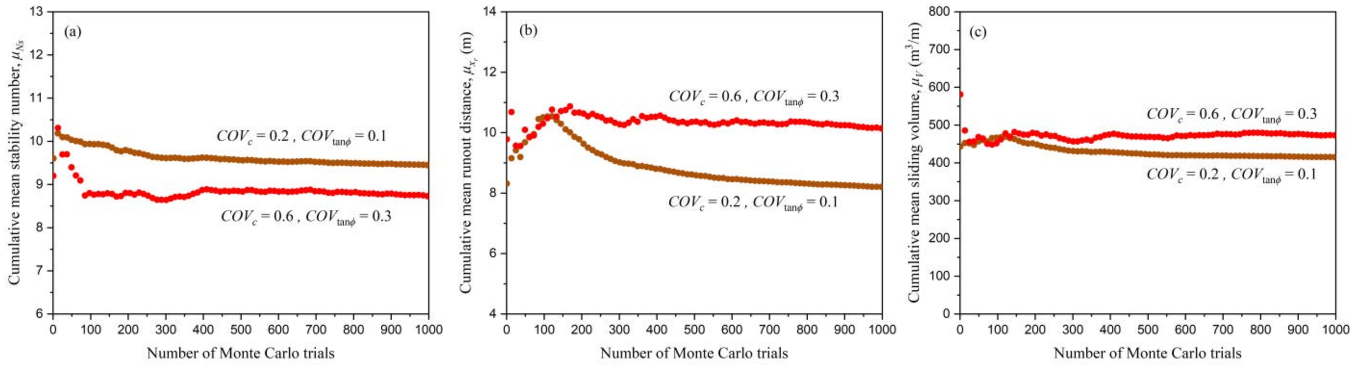

Fig. 3 Cumulative mean value in Monte Carlo trials

To further study the effect of the spatial variability of the strength parameters on the runout characteristics, Fig. 4 depicts histograms of the runout distance, influence distance and sliding volume from *MCS*. The solid curves in Fig. 4 are the estimated log-normal fits. It is obvious that the *COV* of the strength parameters can make different result, which suggests that a large *COV* also leads to a large variation in distribution. For e ample, the runout distance shown in Fig. 4 (a), the range of ln x_r = [1.3 m, 3.2 m] and $COV_{\ln x_r}$ = 0.2373 with *COV* = 0.6 and 0.3, while the range of ln x_r = [1.6 m, 2.8 m] and $COV_{\ln x_r}$= 0.1077 with *COV* = 0.2 and 0.1. Fig. 4 (c) shows that a range of ln V = [.8 m^3/m, 6.2 m^3/m] is the most probable sliding volume. The deterministic result is 6.0342 m^3/m, which is located at the middle of this range. The log-normal fitting parameters also show that the means of the probabilistic analysis are almost consistent with the results of the deterministic analysis. The distribution of influence distance and sliding volume are also coincident with it. Fig. 4 also demonstrates that if using the results obtained by deterministic analysis, there will be nearly half of the possibility of underestimating the destructiveness of the postfailure behavior of slope.

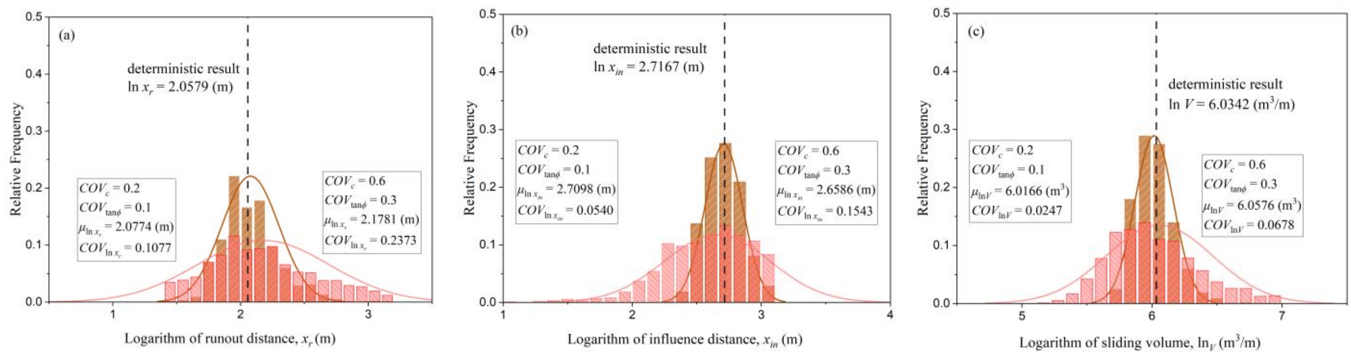

Fig. 4 Histogram of runout characteristics

Conclusion

In this paper, the postfailure behavior of slopes that considered spatial variability was studied using Random Material Point Method. After compared to the homogeneous slope, it was found, due to the spatial variability of soil properties, that the runout distance, influence distance, and the sliding volume showed significant variations, which demonstrated the necessity of taking into consideration soil spatial variability. The spatial variability of soil properties not only affect the stability number, but also affect the runout characteristics of postfailure slope.

Reference

[1] Liu, K., Wang, Y., Huang, M., Yuan, W. Postfailure Analysis of Slopes by Random Generalized Interpolation Material Point Method. International Journal of Geomechanics, 2021, 21, 0402101 .

[2] Liu, X., Wang, Y., Li, D.Q. Investigation of slope failure mode evolution during large deformation in spatially variable soils by random limit equilibrium and material point methods. Computers and Geotechnics, 2019, 111: 301-312.

[3] Vanmarcke, E.H. Probabilistic modeling of soil profiles. J. Geotech. Eng., 1977, 103 (11), 1227–1246.