16th BGA YGES
Newcastle University
July 2022

A novel stochastic pseudo-static approach for $C-\phi$ slopes

P. Shah Malekpoor*[1], S. Lopez-Querol [2]

*pooneh.shahmalekpoor.19@ucl.ac.uk

[1] PhD student (University College London (UCL), London WC1E 6BT, UK),
[2] Associate Professor (University College London (UCL), London WC1E 6BT, UK)

Abstract

Pseudo-static (PS) approaches are most used in the first stages of the regular assessment of seismic slope stability analysis, thus led to the development of several PS slope stability charts. However, it is assumed that the PS coefficient is constant at every location within a field while this is not true in the real case. The spatial variation of the PS coefficient is especially relevant to landslides in wide areas. This research aims at addressing this issue considering the stochastic nature of soils in seismic slope stability analysis within the framework of the Limit Equilibrium Method (LEM) of slices and random fields, termed as 2D-RLEM. Here, the effect of different correlation length levels of the seismic coefficient on the slope probability of failure has been explored under various inclinations of the slope as well as different levels of seismic coefficient. It was observed that perfect correlation assumption for seismic coefficient, K_h, leads to conservative results for slopes with F_{PS}(PS factor of safety)>1.3, while underestimates the possible failure for F_{PS}<1.2.

Introduction

PS approach has been commonly employed compared to rigorous dynamic analysis that entails detailed modelling as well as considerable computation time (Baker et al. 2006). Earthquake loads vary spatially due to the different distances from each considered earthquake rupture to the site, local site effect, and other factors(Baker et al., 2021). The original PS approach does not take such stochastic effects into account. This can be simulated roughly via considering a stochastic nature for the seismic coefficient in a PS approach. Soil strength parameters (such as cohesion and friction angle) are stochastic as well due to different geologic, environmental, and physical–chemical processes (Phoon and Kulhawy 1999). A new methodology has been developed to consider all these stochastic factors and make the simulations more realistic and time-efficient for a seismic slope stability problem.

Methodology

Soil properties and PS coefficient are considered as isotropic stationary Gaussian random fields with lognormal distribution (Javankhoshdel and Bathurst 2014). Values from the literature are adopted for the statistical properties of a theoretical sandy clay slope (Table 1). Cami et al. 2020 provided a summary of literature for correlation structure of different soils (e.g. for mix soils,$\theta_H = 300\ (m), \theta_V = 1.5\ (m)$ and Markovian Autocorrelation Function (ACF) where θ is the scale of fluctuation, Fig. 2). Monte Carlo (MC) simulation has been used which consists of several LE analyses of the slopes (2D-RLEM). For each iteration, samples of random field variables are generated from mrslope2d code (Fenton and Griffiths 2008) and imported as the inputs to home developed code. The slope section is divided into some elements and the imported random values are assigned to each element. Implementing the LEM of slices, each slice base is located within an element, the assigned value of which will be adopted as the random value for the whole slice. Then, F_{PS} of each slip surface is calculated via Bishop simplified in each MC iteration. At the end of each iteration, F_{PS} of the slip surface with the minimum F_{PS} is compared to unity. The slope probability of failure, P_f, is finally calculated as the number of iterations with a F_{PS} less than one to the total number of iterations (i.e. 5000).

Table 1. Statistical attributes used in Fig. 2 results

	Mean	COV
C(cohesion)	10-700 (kPa) (Phoon & Kulhawy 1999)	(10-55)% (Phoon & Kulhawy 1999)
	40(kPa)*	30%*
ϕ (friction angle)	20º-40º (Phoon & Kulhawy 1999)	(5-15)% (Phoon & Kulhawy 1999)
	20º *	10%*
K_h	0.01-0.5 (Tsompanakis et al. 2010)	10% (Tsompanakis et al. 2010)
	0.3*	50%**

*Theoretical values of soil shear strength parameters (representing sandy clay) used for Fig. 2

** To consider a broader range for the variability of PS coefficient

- Theoretical isotropic correlation length values have been assumed for PS coefficient.

Results and Discussion

The presented results are just the preliminary application of this novel methodology on theoretical sandy clay slopes. The effect of spatial variability of PS coefficient for various K_h values and different slope angles has been explored (Fig 1 & 2, respectively). Steep slopes (e.g. 63.5º) were also examined in Figure 2 as the material is clayey. Figure 1 shows that for the specified slope with F_{PS}<1.2, considering a single random variable approach (SRV where θ_{Kh} approaches to infinity, taken as 1000 m in this study), the model is unconservative, while for more stable slopes with F_{PS}>1.3, a SRV approach is conservative. According to Figure 2, the higher the slope angle, the more vulnerable the slope is (as expected) and as the correlation length for K_h approaches twice the height of the slope with any angle, P_f for each slope angle gets more stabilized.

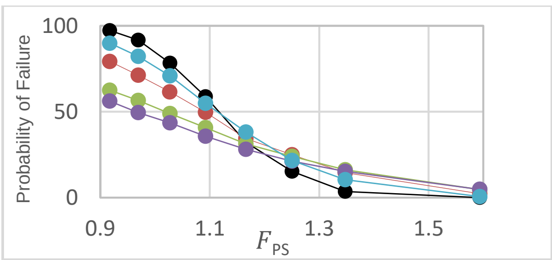

Figure 1. Probability of failure versus F_{PS} for $\mu_C = 46\ (kPa), \mu_\phi = 20\ (\text{deg}), COV_C = COV_\phi = 20\%, \theta_C = \theta_\phi = 5\ (m)$, ACF=Markovian, for θ_{Kh}=5 m(black) ,10 m(blue), 20 m(red), 80 m(green), 1000 m (purple) ;slope height=10 (m); slope angle=27º

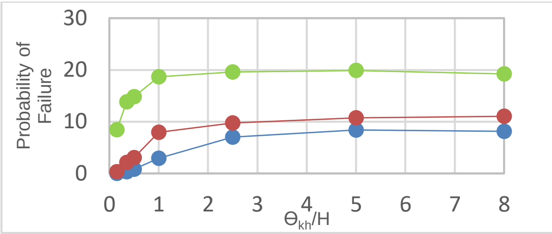

Figure 2. Probability of failure versus standardized correlation length of K_h for different slope angles (blue=27º; red=45º; green=63.5º) using Table 1 statistical parameters; slope height=10 (m)

Future Work

The authors aim at investigating more factors including different slope inclinations and heights for all soil types (e.g. purely cohesive soils undergoing rapid and hence undrained loading), as this novel methodology would make the seismic stochastic analysis much easier and more efficient than before.

References

Baker, R., Shukha, R., Operstein, V. and Frydman, S. 2006. Stability charts for pseudo-static slope stability analysis. *Soil Dynamics and Earthquake Engineering* 26(9), pp. 813–823. doi: 10.1016/j.soildyn.2006.01.023.

Baker, J., Bradley, B. and Stafford, P. (2021). 'Spatially Distributed Systems', in *Seismic Hazard and Risk Analysis*, chapter, Cambridge, Cambridge University Press, pp. 447–482.

Cami, B., Javankhoshdel, S., Phoon, K.-K. and Ching, J. 2020. Scale of Fluctuation for Spatially Varying Soils: Estimation Methods and Values. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering* 6(4), p. 03120002. doi: 10.1061/ajrua6.0001083.

Fenton, G.A. and Griffiths, D. V. 2008. *Risk assessment in geotechnical engineering*. John Wiley & Sons.

Javankhoshdel, S. and Bathurst, R.J. 2014. Simplified probabilistic slope stability design charts for cohesive and cohesive-frictional (c-ϕ) soils. *Canadian geotechnical journal* 51(9), pp. 1033–1045. doi: 10.1139/cgj-2013-0385.

Phoon, K.-K. and Kulhawy, F.H. 1999. Characterization of geotechnical variability. *Canadian geotechnical journal* 36(4), pp. 612–624. doi: 10.1139/cgj-36-4-612.

Tsompanakis, Y., Lagaros, N.D., Psarropoulos, P.N. and Georgopoulos, E.C. 2010. Probabilistic seismic slope stability assessment of geostructures. *Structure and Infrastructure Engineering* 6(1–2), pp. 179–191. doi: 10.1080/15732470802664001.