Proc. of the 6th Intl. Symposium on Reliability Engineering and Risk Management (6ISRERM)
31 May – 1 June 2018, Singapore
Editor(s) Xudong Qian, Sze Dai Pang, Ghim Ping Raymond Ong, Kok-Kwang Phoon

THE EFFECTS OF SAMPLING NUMBER IN SLOPE STABILITY ASSESSMENT

RUI YANG[1] and JINSONG HUANG[1,2]

[1]*Priority Research Centre for Geotechnical Science & Engineering,*
The University of Newcastle, Callaghan, NSW 2308, Australia.
E-mail: rui.yang@uon.edu.au
[2] *School of Civil Engineering and Architecture, Nanchang University, 999 Xuefu Road,*
Nanchang 330031, P.R.China.
E-mail: jinsong.huang@newcastle.edu.au

The traditional analysis of a slope stability proceeds by first testing the soil at a limited number of locations to assess its properties (for example by CPT). Then simplified slope stability analysis methods are commonly employed to design the slope. In reality, limited site investigation tests cannot be representative of the whole slope due to spatial variability of soil properties. Inadequate site investigation may lead to under-design or over-design of slopes. It is therefore necessary, to carry out the site investigation tests which can provide most adequate information for use in design. As such, this paper proposed a framework to quantify the probability of under-design or over-design for different site investigation strategies based on Monte Carlo simulation. A slope is used to assess the reliability of various site investigation scopes. It is observed, that the probability of under-design or over-design decreases as the scope of the site investigation increases.

Keywords: geotechnical site investigation, spatial variability, sampling number, slope stability analysis.

1 Introduction

Slope instability is a serious geotechnical problem that is characterized by various uncertainties (El-Ramly et al. 2002). In practice, a slope design utilizes information from a limit number of geotechnical tests to represent the underlying soil properties. However soil properties often exhibit significant variability from one location to another (Vanmarcke 1977). Thus limit sampling usually lead to inaccurate profile characterizations. The design based on inadequate information can be under-designed which may reduce the initial construction cost but unforeseen conditions can lead to significant costs over-runs or be over-designed which results in additional construction or repair costs. It is obvious that more sampling are conducted, the more reliable the design will be. However the number of soil samples is generally determined by the budget and time considerations placed upon the investigation. Expenditure on site investigation as a percentage of total project cost is low, and ranges typically from a mere 0.1 to 0.3% for engineering projects (Litterjohn 1994). Therefore, it is important to choose effective site exploration scope so that adequate information can be obtained for given budgets. And it is also very important to quantify the reliability level of the design based on limit information.

Research on the effectiveness of geotechnical site investigations is rare in the literature. Jaksa et al. (2003) and Jaksa et al. (2004) proposed and implemented a framework to comparing the effectiveness of various geotechnical investigation programs for footing design. Gong et al. (2014)

discussed the relationship between the level of site exploration efforts and the accuracy of tunnelling-induced ground settlement prediction.

This paper develops a new approach for optimizing sampling numbers in slope reliability assessment. The new method can be used to quantify the probability of making over- or under-design for different investigation strategies. To demonstrate the proposed approach an undrained slope is analyzed based on using soil profile information sampled at specific locations.

2 Methodology

The overall objective of slope stability analysis is to ensure that the slope is safe. The decision about whether the slope is safe or not is made on the basis of a set of samples taken from the site. The slope stability analysis is greatly influenced by the scope of the investigation. A thorough and extensive investigation will imply that accurate knowledge of the site. However, as the scope of the investigation becomes more limited, the analysis will either be under-designed, which result in damage and subsequent rehabilitation, or be over-designed, resulting in construction costs over. So it is necessary to quantify the probabilities of making wrong decision of the design based on different site investigation strategies. Then the optimal strategy can be chosen.

The probabilities of under-designed and over-designed are estimated by Monte Carlo simulation. Figure 1 shows the flow chart of Monte Carlo simulation. The overall philosophy of the framework is compare the stability assessment based on completely knowledge of a site with stability assessment baesd on site investigation.

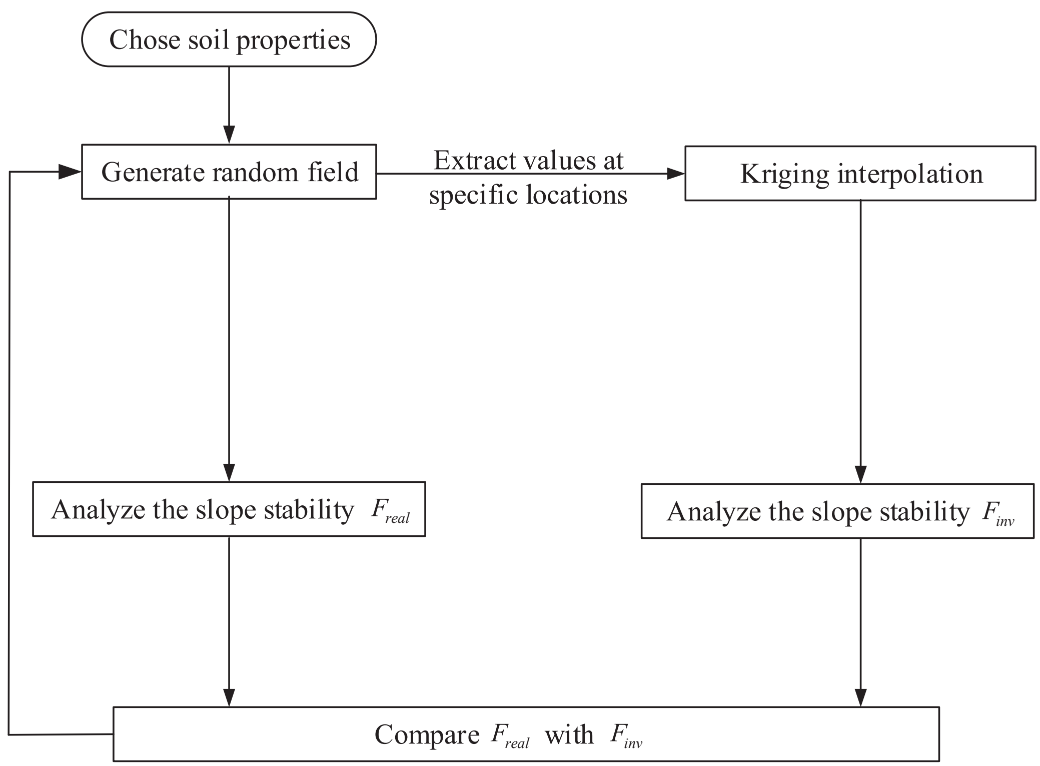

Figure 1. Flow chart for calculating the probability of under-designed or over-designed

Suppose the statistics of undrained shear strength of slopes are given, a slope sample is generated by random field simulation. This slope is treated as a 'real slope'. And the stability of the slope can be analysed by (RFEM Griffiths and Fenton 1993). This stability assessment is based on the assumption that the undrained shear strength of all the elements are known. This is the real state of the slope (F_{real}). However, in reality only limited amount of testing can be conducted. A slope stability analysis needs to be done based on limited samples. The Kriging approach is adopted to estimate the undrained shear strength of the whole slope (Kriged field) based on the known properties. And then a slope stability analysis is conducted based on the Kriged field. This stability analysis is based on limited amount of information. So the stabitliy result is an estimation (F_{inv}). By comparing F_{real} and F_{inv} , performing Monte Carlo simulation, it is possibale to quantify the probability of under-designed and over-designed for a variety of site investigaitons. It is then possible to compare the efficency of one sampling programme with another.

3 Example

An undrained slope is considered with the finite element mesh shown in Figure 2. The slope is inclined to the horizontal at angle $\alpha = 26.6^{\circ}$ (2:1slope), with height $H = 10m$, and depth ratio to a lower firm layer $D = 2$, and soil unit weight $\gamma_{sat}\left(or\ \gamma\right) = 20.0\text{kN/m}^3$, which are all held constant. The undrained shear strength is assumed to be lognormally distributed with the mean $\mu_{C_u} = 50\text{kPa}$ and the standard deviation $\sigma_{C_u} = 25\text{kPa}$. The spatial correlation length is assumed to be isotropic with θ_{c_u} fix at 10m in this paper. The mesh size of $0.5\text{m} \times 0.5\text{m}$ is chosen for the example. Based on the parameters given above, twenty thousand RFEM simulations are performed and the probability of failure (p_f) is found to be 0.17.

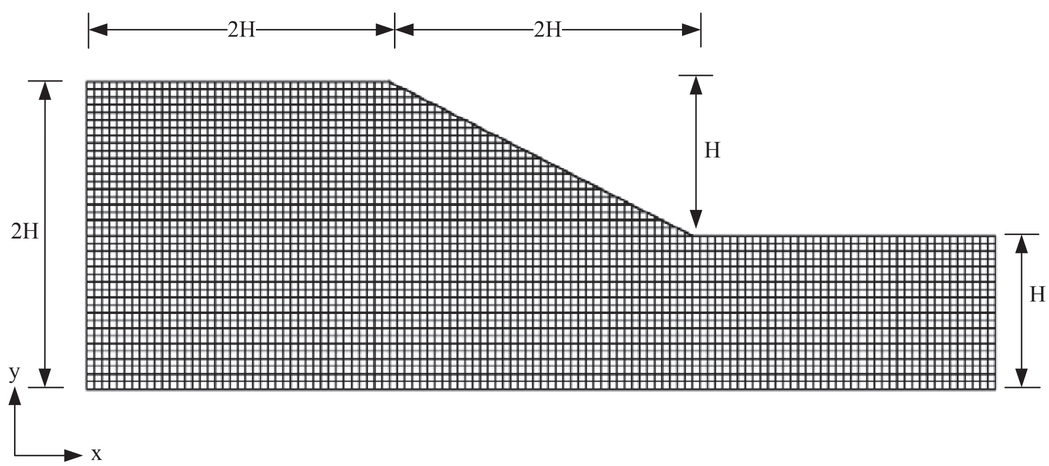

Figure 2 Finite element mesh

The proposed method is adopted to explore the influence of various numbers of samples for the stability analysis of slopes. It is expected that in slope stability analysis problem, increasing the sampling numbers deceases the chances of making an error in the decision about the stability of the slope. In other words, the probabilities of both under-designed and over-designed will be decreased with increasing the numbers of sampling. Five site investigation programmes are investigated. Figure 3 shows the plan views of samples layouts for $n_{cpt} = 1, 2, 3, 4$ and 5 (corresponding to sampling spaces of $\Delta = 30, 20, 15, 12$ and 10m).

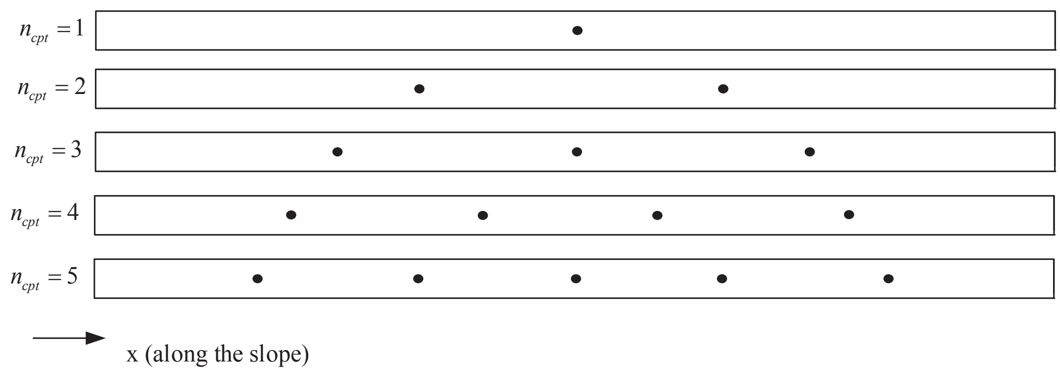

Figure 3 Sampling layouts (plan views) for various numbers of boreholes

Figure 4 and Figure 5 show the influence of the number of samples on probabilities of under-designed and over-designed. These figures indicate that as the number of samples increase, the probabilities of under-designed and over-designed decrease as expected.

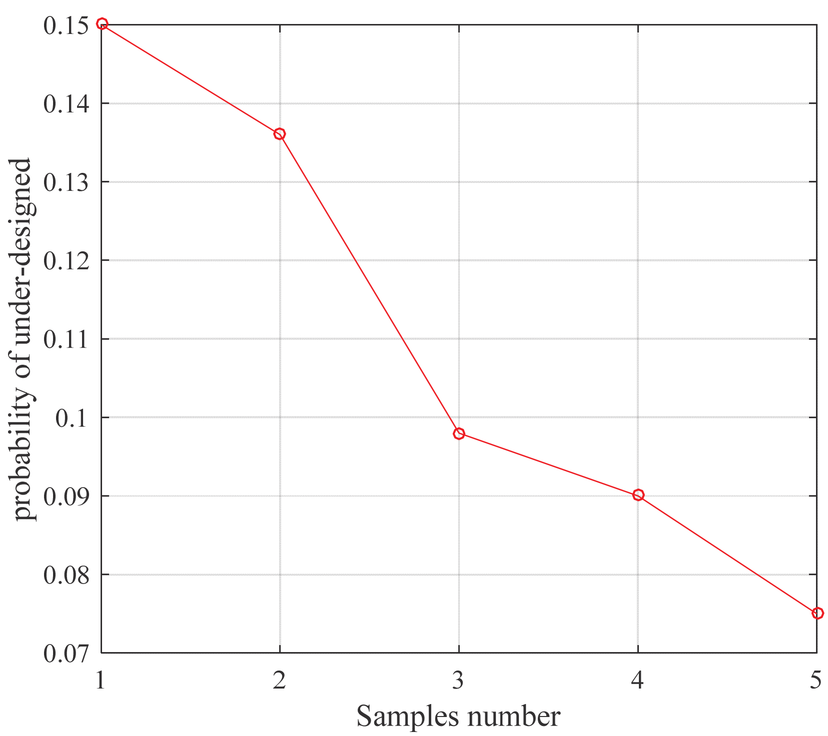

Figure 4 Influence of sampling numbers on probability of under-designed

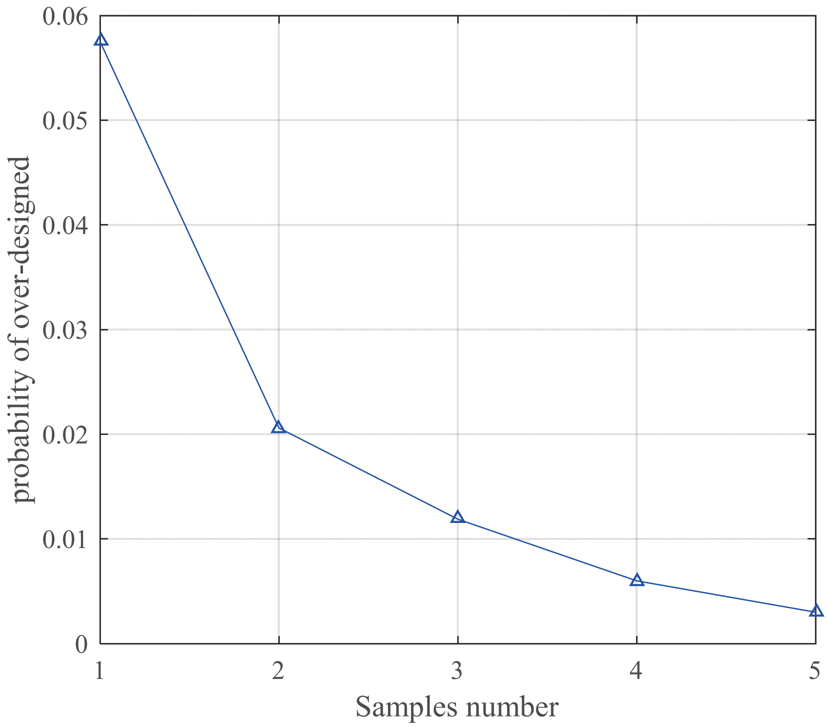

Figure 5 Influence of sampling numbers on probability of over-designed

4 Conclusions

This paper proposed a framework which can quantify the probabilities of under-designed or over-designed for different site investigation schemes. An undrained shear strength slope is considered to study the effect of sample numbers on slope stability assessment by the proposal framework. The results show that increasing samples is effective in decreasing both under- and over- designed probabilities. The same procedure can be used to find the optimal sampling location and discuss the influence of different type of site investigation tests. This highlights the framework's potential use in directing site exploration programmes.

References

El-Ramly, H., Morgenstern, N. and Cruden, D. Probabilistic slope stability analysis for practice. *Canadian Geotechnical Journal,* 39**,** 665-683,2002.

Gong, W., Luo, Z., Juang, C. H., Huang, H., Zhang, J. and Wang, L. Optimization of site exploration program for improved prediction of tunneling-induced ground settlement in clays. *Computers and Geotechnics,* 56**,** 69-79,2014.

Griffiths, D. and Fenton, G. A. Seepage beneath water retaining structures founded on spatially random soil. *Geotechnique,* 43**,** 577-87,1993.

Jaksa, M., Goldsworthy, J., Fenton, G., Kaggwa, W., Griffiths, D., Kuo, Y. and Poulos, H. Towards reliable and effective site investigations.2004.

Jaksa, M., Kaggwa, W., Fenton, G. and Poulos, H. (2003). A framework for quantifying the reliability of geotechnical investigations. *9th International Conference on the Application of Statistics and Probability in Civil Engineering.*

Litterjohn, G. S., Cole, K.W. & Mellors, T.W. *Without Site Investigation, Ground is a Hazard*, 1994.

Vanmarcke, E. H. Reliability of earth slopes. *Journal of the Geotechnical Engineering Division,* 103**,** 1247-1265,1977.