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Engineering Geology for Society and Territory – Volume 2

Landslide Processes

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Cover illustration: Landslide affecting the hill of Ruinas, Oristano, Italy. On February, 2005, the phenomenon invaded the road path and caused difficulties to the traffic. During the emergency, to ensure safety of the road traffic, a particular monitoring and early warning system was deployed. *Photo*: Daniele Giordan.

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Comparative Study of System Reliability Analysis Methods for Soil Slope Stability

240

Xiao Liu, D.V. Griffiths, and Hui-ming Tang

Abstract

Generally, a soil slope might have numerous potential slip surfaces, and each of them can lead to a failure of the slope. So, the soil slope's reliability analysis is naturally a system reliability problem, and the overall failure probability may be larger than that of any single slip surface. This paper focuses on the comparative study of system reliability methods for soil slopes. Initially, a rigorous analytic solution is presented, followed by the classification of the existing analysis methods into four categories. Then, a comparison study between these categories is carried out. We conclude that the Monte Carlo-based analysis is best suited to resolve the system reliability assessment of soil slopes and that within this category the finite-element-based approach is superior to the limit-equilibrium-based one. Other methodologies tend to underestimate the failure probability of the soil slope system.

Keywords

Slope stability • System reliability • Multiple failure modes • Probabilistic methods • Monte Carlo simulation

240.1 Introduction

A slope reliability analysis often reveals a huge number of possible slip surfaces, which combine into an almost infinite number of failure models. A well designed reliability analysis should recognize that slope failure analysis is a system reliability problem and must reveal an overall slope failure probability. Any reliability analysis that does not confront this reality is weakened by simplification.

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Cornell (1971) was the first to point out that the overall slope failure probability may be larger than that of any single slip surface, and this fact has been successively confirmed by many researchers (e.g., Oka and Wu 1990; Chowdhury and Xu 1995; Huang et al. 2010; Zhang et al. 2013). However, a considerable number of existing studies (e.g., Hassan and Wolff 1999) still focus on the failure probability along a single slip surface (e.g., the slip surface with maximum failure probability labeled the probability critical slip surface) instead of overall failure probability that involves multiple failure modes.

Because the system reliability analysis of slopes is generally more difficult to achieve than calculation of a single mode, researchers seek and use methods that can simplify the task. Unfortunately, most of these methodologies tend to underestimate the failure probability of the system which can cause serious consequences in engineering practice. So efficacy evaluation of the different methods is essential, and it is critical to recognize their inherent error characteristics. For decades there has been little research aimed at exploring this fundamental topic.

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number of slip surfaces involved in the slope system is not limited within the Monte Carlo framework. Increasing the number of slip surfaces does not increase the difficulty of the algorithm programing and if the FEM is applied, it can deal with the infinite series system of slopes. Second, one no longer needs to evaluate separately the complex association between each slip surface because the Monte Carlo simulation automatically satisfies this requirement. The problem of system reliability is unresolvable by any current analytic solution because a soil slope can have infinite potential slip surfaces and the huge number of complex associations between the slip surfaces produce a type of "dimension disaster". In contrast, the third category, which can evaluate an unlimited number of slip surfaces and automatically evaluates the associations between each slip surface, is especially suitable to the system reliability analysis of soil slopes. Moreover, except for current limitations of computational efficiency, FEM is superior to LEM, so improvement in the efficiency of the FEM algorithms is a promising direction of future development. In this field, Huang et al. (2010) have suggested an efficient method based on technology of response surface.

240.5 Conclusion

In the complex reality of natural conditions, a slope reliability analysis must be considered a system reliability problem. The existing methodologies of system reliability analysis can be divided into four categories, and three of them can approach the infinite series system of soil slopes. Theoretical studies have shown that the third category, based on Monte Carlo simulation, has a much more solid theoretical foundation than the other categories. If the same system is evaluated by all three of these categories of methods, the third category will yield the largest failure probability and will be much closer to the true solution, followed by the second category, with the first yielding the smallest one. Moreover, in the third category, the FEM-based approach is superior to the LEM-based one.

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