17th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2013, Istanbul, Turkey, 10-11 September 2013

RISK AND RELIABILITY ANALYSIS OF SLOPE STABILITY-DETERMINISTIC AND PROBABILISTIC METHOD

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ABSTRACT
Slope stability analysis is the most interesting area in geotechnics design. Uncertainty inherent in geotechnical properties has caught more and more attentions from researchers and engineers. A factor of safety calculated by traditional deterministic analyses methods can not represent the slope stability exactly. Consequently, reliability analyses and non-deterministic methods, which include probabilistic and non probabilistic methods, have been applied widely. In short, combining the probabilistic analysis with deterministic slope stability analysis is common practice nowadays. It cannot be regarded as a completely new slope stability analysis method, but just an extension of the slope deterministic analysis in order to understand a problem from a slightly different perspective and treat uncertainties systematically in analysis of slope. The slope failure probability calculated by risk analysis is a kind of complement of safety factor.
In this paper, two widely used methods are applied in probabilistic analysis of slope stability in open pit mine “Potrlica”, Pljevlja in Monte Negro, Monte Carlo simulation and FORM (First Order Reliability Method) enforced with the RSM (Response Surface Method). These methods are used to obtain slope probability of failure with sufficient accuracy, but with simplified calculation and formulas.
Keywords: slope stability, reliability analyses, probabilistic method, deterministic method.

1. INTRODUCTION
The slope formed in the limestone mass under the angle of 65 °, allows the best utilization of coal mining in the open pit mine "Potrlica" in Pljevlja. The slope, important for further exploitation of coal, comes to the edge of the sorting object. In order to preserve the object, the slope must be stable over 6 months.

2. DETERMINISTIC METHOD
The stability of imaginary sliding body, which is in contact with the surrounding soil through the sliding surface, is analyzed with the method of limit equilibrium. The sliding body is divided into a series of vertical slats. The composition of these sections is, without introducing assumptions about their stiffness, statically in determinate. The tangential and normal stress at the bottom of each section

of sliding surface is determined by the analysis of the equilibrium conditions of forces acting on each of the sections and introduction of assumptions in order to remove indeterminacy of static system. The analytical method of Bishop and Morgenstern-Price, which contains the equilibrium conditions separately for each section of the whole sliding body, will be probabilistically analyzed.

Bishop's method introducing two assumptions in the calculation: ignoring the impact of tangential forces acting between the sections and determining the value of the tangential force along the sliding surface. The Morgenstern-Price's method as large advantage sover the Bishop's method. It considers normal and tangential forces between the sections (as opposed to Bishop's method), satisfies the equilibrium conditions of forces and moments, and permits the use of various loading sections. Solving of these complex equations by iterative methods is too complicated. The data are obtained by using Geo Studio 2007 with tool SLOPE/W specialized in limit conditions of equilibrium. The calculation is performed for the 50 assumed sections, thus increasing the accuracy of the calculation.

3. PROBABILISTIC METHOD

Strength, stiffness of materials and geotechnical design of any system is based on the following parameters: module us of elasticity (E), unit weight(γ), cohesion (c), angle of friction(φ), Poisson's ratio(ν) and others. All these parameters are obtained from laboratory testing samples from the field. The calculation of slope stability includes a variety of uncertainty, which initiates safety factor of 1.5to 3.0.Selection of the safety factor is a simple and one-sided, but does not take, in the rational extent, variety of uncertainty in calculation. In order to infiltrate the uncertainty in calculation, probabilistic analysis will be used. In this approach, the input parameters are treated as random variables, analyzing their influence on the output parameters. Risk analysis is used to obtain a better solution of the problem and to assist in the decision-making process.

In the probabilistic analysis, explicit or implicit connection between the input parameters and the output response is necessary but difficult to achieve. It is only possible for simple cases and even when is accomplish is too complicated to analyze by conventional probabilistic approach. In such circumstances, the concept of RSM (Response Surface Method) can be used to establish explicit functional relationship between the input random variables and output responses. The advantage of this method is that getting results are compatible with computationally demanding approaches. The main idea of RSM is to replace complicated functions for determined safety factor (in this case, Morgenstern-Price and Bishop) with a new, approximate functions and also analyzing the effect of the important factors on the results.

In the case of the probabilistic slope analysis, two random variables are cohesion and angle of friction, with five coefficients, so that the safety factor can be written as an approximate function of the following form:

$$F_S(c,\varphi) = a_1 + a_2 c + a_3\varphi + a_4 c^2 + a_5\varphi^2 \quad ... (1)$$

The limit state function will then be the factor of safety minus one, thus:

$$g(c,\varphi) = F_S(c,\varphi) - 1 \quad ... (2)$$

It was assumed that there was no correlation between the variables and that the variables were normally distributed. In order to find constants in equation (1), five equations with five coefficients were run. Factors of safety for both methods are obtained in SLOPE/W. Solving for the five constants yields the limit state function:

$$g(c,\varphi) = a_1 + a_2 c + a_3\varphi + a_4 c^2 + a_5\varphi^2 - 1 \quad ... (3)$$

By implementing these features in VaP (software package), probability of failure are obtained, using to methods: Monte Carlo and FORM (First Order Reliability Method).

3.1 Morgenstern-Price:

$$g(c,\varphi) = 0{,}0025c + 2.176\varphi + 0{,}000000055c^2 - 0{,}04\varphi^2 - 30{,}58 \quad ... (4)$$

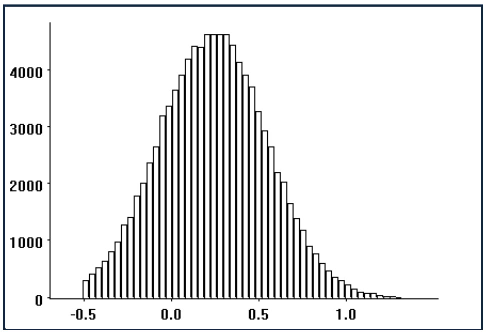

Figure 1. Probability distribution for a Monte Carlo analysis of Morgenstern-Price's limit state function

	Crude Monte Carlo	FORM
p(g<0)	0,225	0,212
β	0,760	0,800

Table1. Calculation results (probability of failure and reliability index β) for Morgenstern-Price's limit state function

3.2 Bishop:

$$g(c,\varphi) = 0{,}00295c + 0{,}744\varphi - 0{,}00000036c^2 + 0{,}0133\varphi^2 - 11{,}46 \quad ... (5)$$

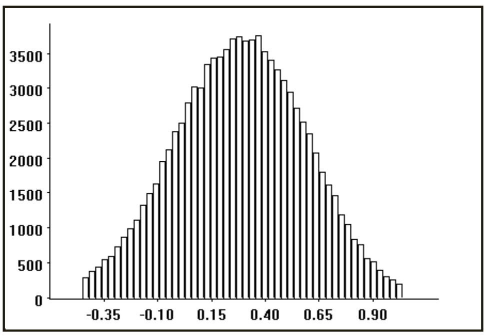

Figure 2. Probability distribution for a Monte Carlo analysis of Bishop's limit state function

	Crude Monte Carlo	FORM
p(g<0)	0,183	0,183
β	0,900	0,903

Table2. Calculation results (probability of failure and reliability index β) for Bishop's limit state function

4. CONCLUSION

The results of the safety factor obtained in software SLOPE/W, as well as the probability of failure are consistent with the simplifications introduced in the Bishop's method. In fact, because of neglecting inter lamellar forces and respecting assumption that the sliding planes are circle, a slightly higher reliability index are obtained, ie. lower probability of failure. The difference in the obtained failure probabilities with Morgenster-Price's and Bishop's method is 13.5%, which indicates that among exact methods significant difference in the results can be expected. This information allows easier selection of methods depending on the importance of the results obtained.

Design of any building structure includes a risk. This is especially true for the slope, where natural materials, and the changing external conditions affecting its stability. The amount of risk involved in the calculation can not be quantified. If the slope is not a conservative designed, can increase the chances of its collapse. On the other hand, the negative economic consequences of design are too free and too conservative. Acceptable level of risk in this case, for temporary slope are 0,1. The resulting probability of failure for the Morgenstern-Price method and Bishop's are twice as high (Table 1 and Table 2). Such a high probability of risk is not acceptable even for short-term requirements on the open pit mine. Therefore, all costs of slope sanitization seem justified. The goal of this research is to bring reliability analysis and the results of probability analysisto engineers who are daily engaged in geotechnical problems. The parameters used in the calculation are unreliable, and their variation has a large impact on the final outcome, which engineers are not fully aware of.

5. REFERENCES

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