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Stability Analysis of a Tunnel in Hydrostatic Conditions Using Different Reliability Methods in @Risk and RT Software

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1. Introduction

Drilling underground spaces disturbs the balance of stresses in the excavated environment and creates a plastic zone with the potential for degradation around this space. Accordingly, it is necessary to analyze the stresses and study the radius of the plastic area and predict the support for it. Changes in soil properties, that is, the uncertainty of its parameters cause errors in deterministic analyses. In order to consider the uncertainty in engineering analysis, probabilistic methods and reliability are presented. In these methods, the parameter that is finally obtained using different numerical and simulation methods is the probability of failure.

In this research, using Hooke-Brown and Mohr Columbus relations, a method is presented for analyzing the stability of two tunnels (in different conditions) using powerful reliability methods including first-order reliability method, second-order reliability method and the Monte Carlo Simulation in new RT and @Risk software.

2. Reliability assessment methods

Given the complexity of calculating integrals in relation to the probability of failure, researchers have sought to find ways to approximate reliability. This defines a function called the limit state function that expresses system performance as failure or success. This function may be linear or nonlinear. In the first-order method, depending on the nonlinearity of the function, the failure probability calculations are erroneous. The function is estimated with a page or cloud page. When the limit state function has a large curvature, the linear approximation reduces the accuracy of the calculations. In nonlinear functions, the second-order method approaches a correct answer with the help of a quadratic approximation. This method is in fact an evolution of the first-order method. In addition to analytical methods, Monte Carlo simulations estimate the probability of failure. Monte Carlo simulation is random sampling to artificially simulate a large number of tests and observe their results in the analysis of the reliability of structures in the simplest form.

3. Analysis and results

In this section, the results obtained from the reliability analysis related to the stability of the two tunnels are presented. The first tunnel is a circular one drilled in a homogeneous, isotropic, and elastic space and is subject to a hydrostatic stress field and uniform internal support pressure (P_i). The stability analysis of this tunnel is examined in three types of P_i conditions, which include the values of 0, 0.3, and 0.8 MPa, and in each study, its value is deterministic entered in the relations. In addition, other deterministic variables are the $P_0 = 2.5$, Poisson's ratio $\nu = 0.3$ and the tunnel radius r_0. Moreover, random variables are cohesion, friction angle, and deformation modulus.

Analyses for each tunnel have been performed in two types of limit state functions and three reliability methods, which show that in different values of P_i, different values of failure probability are obtained.

The second tunnel, like the first tunnel, is a circular tunnel that is drilled in a homogeneous, isotropic, and elastic space and is subjected to hydrostatic stress field and uniform support pressure. Its deterministic variables are the same as the first tunnel, but the support pressure is considered as a random variable.

4. Conclusion

Studies have shown that in the case of the first limit state function in the large probability of failure (in the first tunnel with zero support pressure), the first-order reliability method and the Monte Carlo simulation act almost similarly. On the other hand, in the case of very small probability of failure, all three output methods are close to each other. Monte Carlo simulation, however, at very small probability values and very high accuracy, requires the production of large amounts of random data and the simulation of each of them has a high computational cost. In this regard, its use in these conditions is not recommended.

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Table 1. Estimation of the failure probability in the first limit state function

@Risk software	RT software					Support Pressure
MCS	MCS	SORM		FORM		
P_f (%)	P_f (%)	P_f (%)	β	P_f (%)	β	
24	23.79	25.77	0.65	24.19	0.7	0
0	0.06	0.06	4	0.06	3.2	0.3
0	0	4.7×10^{-14}	7.45	4.7×10^{-14}	7.45	0.8

Table 2. Estimation of the probability of failure in the second tunnel

@RISK		SORM (RT)		Type of Method
$G_2(X)$	$G_1(X)$	$G_2(X)$	$G_1(X)$	
4.1	4.9	3.5	4.5	(%)Pf

The results of sensitivity analysis on variables showed that the deformation modulus (in all analyzes) has a very high importance and in the analysis in terms of importance and impact has the first priority. Moreover, the results showed that the reliability index is highly dependent on the support pressure. The tunnels under study have a high probability of failure without support.