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Tunnelling and Underground Space Technology 20 (2005) 479–486
Tunnelling and Underground Space Technology incorporating Trenchless Technology Research
www.elsevier.com/locate/tust

Risk analysis for determination of a tunnel support pattern

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Received 21 September 2004; received in revised form 10 March 2005; accepted 25 March 2005
Available online 10 May 2005

Abstract

Rock mass is inhomogeneous in nature. Data for underground structure designs are mainly obtained from site investigations and tests, but they are very limited. For this reason, uncertainty exists in the process of constructing underground structures in a rock mass. In the design a tunnel support pattern, the most important parameters such as advance rate and excavation method must be determined optimally. However, it is difficult to determine these parameters quantitatively. In addition, if these parameters are determined incorrectly, unexpected risk occurs such as the decrease in the tunnel stability or economic loss due to excessive amount of supports.

In this study, a methodology to determine an optimal support pattern and advance rate for the design of a tunnel is introduced based on risk analysis. It can be confirmed quantitatively that the more the tunnel is supported, the higher the reliability index becomes and the more stable the tunnel is predicted to be. Also an optimal support pattern and advance rate can be determined quantitatively by performing a risk analysis considering the construction cost and the cost of losses that can occur due to the collapse of a tunnel.

Keywords: Risk analysis; Factor of safety; Monte Carlo simulation; Tunnel support pattern

1. Introduction

Rock masses, in general, are inhomogeneous. The data for underground structure designs are mainly obtained from investigations and tests, but they are very limited. Therefore, a great deal of uncertainty is included in the construction of underground structures in a rock mass. In a tunnel design, the main design parameters such as support pattern, advance rate, and excavation method must be optimized. However, this optimization is difficult, and if wrong decisions are made, unexpected risks such as decrease of the tunnel stability, economical loss due to the collapse of a tunnel, excessive supporting, etc. may occur.

Design engineers and decision makers carry out parameter optimizations not only by structuring a problem of interest but also by performing a risk (Isaksson, 2002). For example, the main elements and flow for underground construction as shown in Fig. 1 can be considered in a decision analysis analysis (Sturk et al., 1996; Sturk, 1998).

In this study, a methodology is introduced to determine an optimal support pattern and advance rate for a specific section of a tunnel based on risk analysis. In particular, a shear strength reduction technique proposed by Dawson et al. (2000) was adopted to estimate the stability of a tunnel quantitatively. Also Monte Carlo simulation technique was used to estimate the probability distribution of the safety factor of a tunnel. To this end, the uncertainty embedded in the deformation modulus, cohesion, and friction angle are only

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doi:10.1016/j.tust.2005.03.002

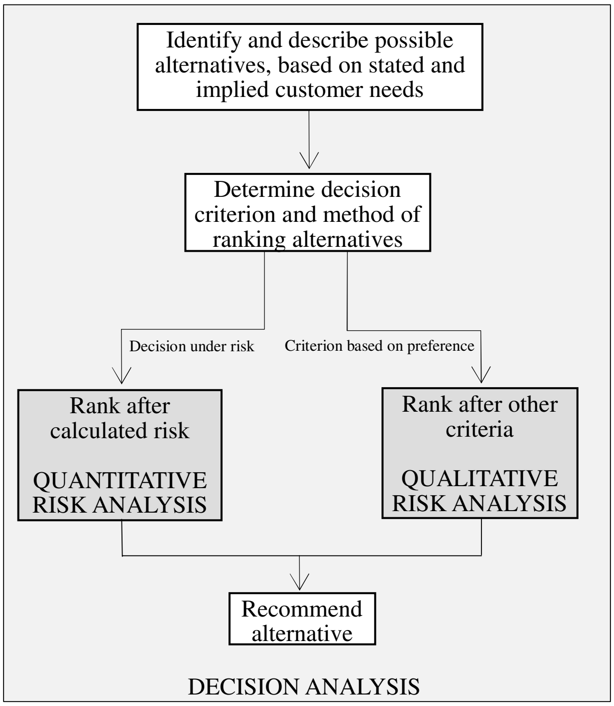

Fig. 1. Recommended decision process for underground construction (after Sturk, 1998).

considered for the risk analysis. Fifty random values distributed normally were generated for each ground properties.

2. Quantification of uncertainty

When a model is a function of several variables, there are three possible ways to quantify the uncertainty related to the model (Kalamaras, 1996): deterministic analysis, sensitivity analysis, and simulation approach. In deterministic analysis, average values of the variables are used as inputs for the simulation model. The single values do not give any information about the variability of the input variables. In a sensitivity analysis, a single parameter is systematically varied while all the other parameters are held constant. Although this simple approach provides an understanding of the effect of each parameter on the overall behavior of the model, it produces an output with limited practical use. In the simulation approach, samples are taken repeatedly from the probability density functions of the variables and used to calculate the output of a model until its distribution is obtained with a desired accuracy. This approach is known as the Monte Carlo simulation method.

The Monte Carlo simulation method is used to generate random variables for a model that is a function of several variables. In this method, a large number of values for each variable are randomly selected and model calculation is performed repeatedly with each generated random value. Finally, a distribution of the model can be obtained as an output. Though this approach is often criticized as an approximating method, a distribution with a desired accuracy can be obtained by increasing the number of simulations. The shortcomings of this approach are the limited number of random values generated by an algorithm and increased computation time due to repetition. However, these shortcomings can be overcome by establishing the structure of a model properly, as is often the case.

In this study, the Monte Carlo simulation technique was used to quantify the uncertainty of tunnel stability which results from the inaccuracy of ground properties such as deformation modulus, cohesion, friction angle, etc.

3. Risk analysis

The generally accepted way to express performance uncertainty is to describe it as a distribution and to relate it to a fixed limit (Fig. 2) or to a required performance that is also expressed in terms of a distribution (Fig. 3). Einstein (1996) stated that this approach could be used as a substitute for the safety factor concept.

Instead of using distributions, one can use the so called "reliability diagrams", which show how far the predicted performance is shifted from the critical performance (Fig. 4). Reliability can also be expressed analyt-

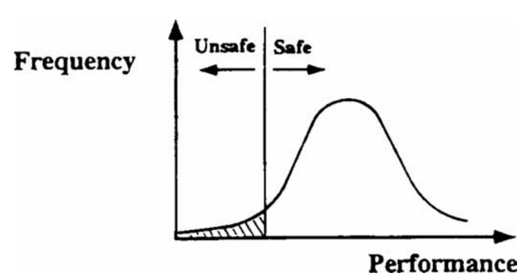

Fig. 2. Performance distribution and fixed performance limit (after Einstein, 1996).

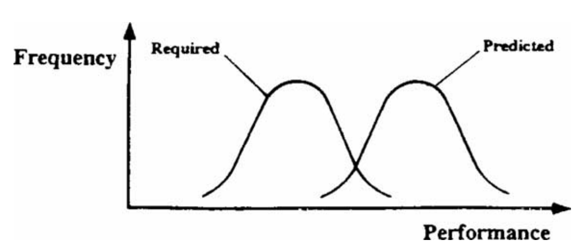

Fig. 3. Distribution of predicted and required performance (after Einstein, 1996).