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Sensitivity analysis of influencing parameters in cavern stability

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ABSTRACT

In order to analyze the stability of the underground rock structures, knowing the sensitivity of geomechanical parameters is important. To investigate the priority of these geomechanical properties in the stability of cavern, a sensitivity analysis has been performed on a single cavern in various rock mass qualities according to RMR using Phase 2. The stability of cavern has been studied by investigating the side wall deformation. Results showed that most sensitive properties are coefficient of lateral stress and modulus of deformation. Also parameters of Hoek–Brown criterion and σ_c have no sensitivity when cavern is in a perfect elastic state. But in an elasto-plastic state, parameters of Hoek–Brown criterion and σ_c affect the deformability; such effect becomes more remarkable with increasing plastic area. Other parameters have different sensitivities concerning rock mass quality (RMR). Results have been used to propose the best set of parameters for study on prediction of sidewall displacement.

1. Introduction

At present, a variety of numerical methods are available for stability analysis of rock masses. There are many factors and parameters that affect the rock mass stability. Many authors have carried out sensitivity analysis on parameters influencing stability of underground openings using numerical methods. Shuangjian et al. investigated the sensitivity of factors, influencing the strength of jointed rock [1–4]. Starzeca and Andersson studied sensitivity of geometric parameters of probable blocks in underground openings [5]. Bhasin and Hoeg studied sensitivity of joint parameters in a large cavern in Himalaya [6]. Schlueter and Pruess performed sensitivity studies on gas release from an underground rock cavern [7]. Kabala and Milly studied sensitivity of flow in unsaturated heterogeneous porous media [8]. McElwee et al. performed analyses on influencing parameters in slug test [9]. Yeung and Tinucci carried out sensitivity analysis of the conceptual design of a repository in rock salt to ascertain influences of maximum salt temperature, maximum entry temperature, and entry closure [10]. Beiki et al. applied sensitivity analysis using neural network to estimate the deformation modulus of rock mass [11]. Brunton et al. identified influencing parameters in sublevel caving material flow behavior, and ore recovery and dilution [12]. Determining priority of these parameters can be very useful during computation and estimation of them. Sensitivity of these parameters varies from case to case. The parameters can also be utelized in a probability risk analysis in further studies [13]. Change in rock mass properties or change from elastic to elastoplastic behavior causes a change in priority of parameters sensitivity. This paper attempts to determine the priority of sensitive parameters effecting underground opening stability, using RMR rating system.

2. Computational model

Two-dimensional FEM program, Phase 2 has been used to model and analyze the stability of the underground structures. Fig. 1 shows the cavern that is used in numerical analysis.

The following simplifications and assumptions have been made:

- The surrounding rock mass is homogeneous and continuous. The joint effect is considered using the equivalent deformation module, E, from the in situ measurements.
- The initial in situ stress is uniformly distributed within the computational domain and the two principal stresses act in horizontal and vertical directions.

The stability of the underground structure complex is reflected by the maximum horizontal deformation of the sidewall of the cavern. The parameters used for the sensitivity analysis include deformation module E; Poisson's ratio v; parameters of Hoek–Brown criterion mb, s; uniaxial compressive strength (σ_c), and coefficient of lateral stress (K). For the above exercise, the basic parameter set Table 1. Possible varying range set has been considered according to ±20% of basic parameters.

3. Method of sensitivity analysis

Sensitivity analysis method is the method used to analyze the stability of a system [7]. Given a system whose character, P, is

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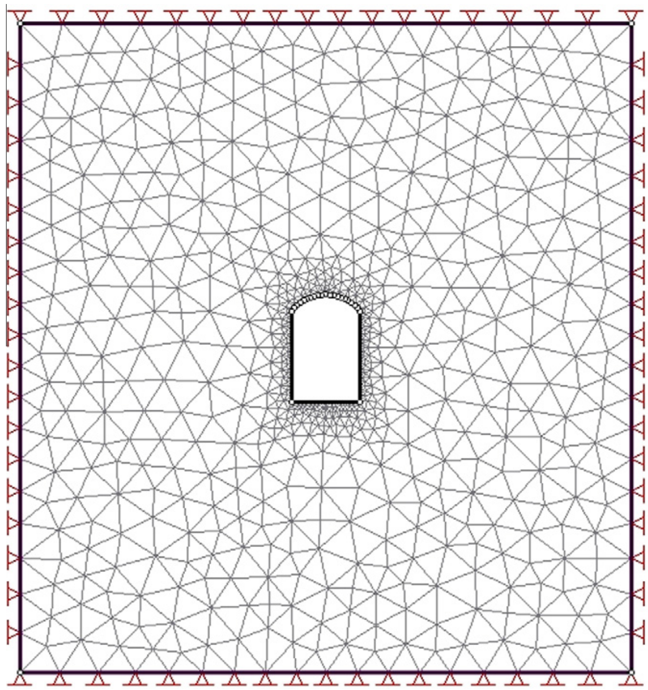

Fig. 1. Cavern of 33 m × 52 m cross section.

Table 1
Basic parameter set.

RMR	K	E (GPa)	UCS (MPa)	mb	s	v
87	1.5	74	60	16.825	0.1323	0.25
75	1.5	56	340	10.961	0.0357	0.25
60	1.5	13.335	119	6.01	0.007	0.25
54	1.5	11.9	100	3.546	0.0054	0.28
47	1.5	4.35	70	2.12	0.0013	0.27
35	1.5	3.162	113.4	1.28	0.0007	0.30

governed mainly by n factors of $\alpha=\{\alpha_1, \alpha_2, \ldots, \alpha_n\}$, $P = f\{\alpha_1, \alpha_2, \ldots, \alpha_n\}$. Under a reference state of $\alpha^* = \alpha_1^*, \alpha_2^*, \ldots, \alpha_n^*$, the character is described by P^*. The sensitivity analysis is to, let the above individual factors vary within respective possible range and then analyze both tendency and extent to which the character of the system, P, departs from the base state due to the variation of the factors.

The first step of sensitivity analysis is to establish the system model, i.e., the functional relation between the system character and the factors, $P = f\{\alpha_1, \alpha_2, \ldots, \alpha_n\}$. This relation should be, if possible, described by analytical expression. In the case of a complex system, it can be expressed by numerical method or through presentation of graphic chart. It is a key step of the effective analysis on parameter sensitivity to establish a model that reflects the system with the reality as fully as possible. The basic parameter set should be given after the system model has been established. The basic parameter set should be established to reflect the subjects considered. For example, when the sensitivity of the stability of an underground project to the variation of rock mass parameters is to be studied, the suggested rock mass parameters of the in situ rock mass can be used as the basic parameter set. Once the basic parameter set is determined, the sensitivity analysis can be performed on each parameter [14].

In dimensionless analysis, the sensitivity function and the sensitivity factor are defined in dimensionless terms. The ratio of the relative error (δ_p), of the system character P ($\delta_p = |\Delta P|/P$) to the relative error of parameter α_k ($\delta_{\alpha k} = |\Delta\alpha_k|/\alpha_k$) is defined as the sensitivity function, $S_k(\alpha_k)$, of the parameter α_k.

$$S_k(\alpha_k) = \left(\frac{|\Delta P|}{P}\right) \Big/ \left(\frac{|\Delta\alpha_k|}{\alpha_k}\right) = \left|\frac{\Delta P}{\Delta\alpha_k}\right| \frac{\alpha_k}{P} \quad k = 1, 2, \ldots, n \tag{1}$$

When $|\Delta\alpha_k|/\alpha_k$ is small, the function of $S_k(\alpha_k)$ can be expressed approximately as

$$S_k(\alpha_k) = \left|\frac{d\varphi_k(\alpha_k)}{d\alpha_k}\right| \frac{\alpha_k}{P} \quad k = 1, 2, \ldots, n \tag{2}$$

From Eq. (2), the sensitivity function curve of α_k can be obtained, which is shown in Fig. 2.

Given $\alpha_k = \alpha_k^*$, the sensitivity factor S_k^* of the parameter α_k is obtained as:

$$S_k^* = S_k(\alpha_k^*) = \left(\frac{d\varphi_k(\alpha_k)}{d\alpha_k}\right)\alpha_k = \alpha_k^* \frac{\alpha_k^*}{P^*} \quad k = 1, 2, \ldots, n \tag{3}$$

where S_k^* and $k = 1, 2, \ldots, n$ are a group of non-negative dimensionless real numbers.

The higher S_k^* is, the more sensitive P is to α_k. Based on comparison between different S_k^* values, one can give synthetic assessment on the sensitivity of various factors [14].

4. Results and discussion

All parameters have been analyzed one by one using the method stated earlier. When analyzing the effect of α_k on the characteristic of the system, P, the parameter α_k in the set is varied within a possible range while the remaining parameters are kept constant. The resulted relations for all parameters are shown in Table 2. The procedure to analyze the coefficient of lateral stress K and the deformation module of E is described below.

The values of E and K are adjusted step by step to calculate the maximum horizontal displacement, u, of the sidewall of the cavern. Curves representing u–E and u–K are plotted from the computing results, as shown in Fig. 3.

The function relations of u–E and u–K have been obtained from the curves and can be expressed as:

$$u_E = \frac{574.1}{E} \tag{4}$$

$$u_K = 5.548K - 0.564 \tag{5}$$

From the Eq. (2) we have two sensitivity functions of $S_E(E)$ and $S_K(K)$:

$$S_E = \left|\frac{du}{dE}\right| \frac{E}{u} = \frac{574.1}{Eu} \equiv 1 \tag{6}$$

$$S_k = \left|\frac{du}{dE}\right| \frac{K}{u} = 1 + \frac{0.564}{u} \tag{7}$$

where u is cavern sidewall displacement. By substituting $E^* = 74$ GPa and $K^* = 1.5$ into Eqs. (6) and (7) the sensitivity factors S_E^*, S_k^*

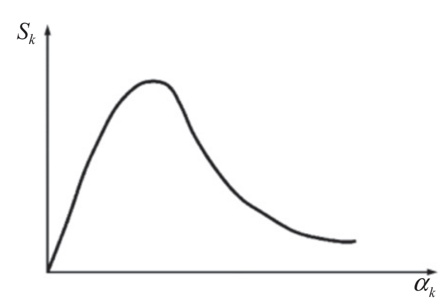

Fig. 2. Curve of sensitivity function $S_k - \alpha_k$.