J. ĎUROVE, M. MARAS, P. VAVREK, J. DAŇKO

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STABILITY CALCULATION OF UNDERGROUND CHAMBERS FORMED BY SALT LEACHING

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The stability problem of caverns in the connection with the intention of their secondary utilisation is in more general way formulated as the task: to solve the stability of underground opening at which a breaking of surrounding rocks by occurs exceeding the limit of the tensile strength induced by secondary stresses.

Key words: *rock mechanics, salt mining, salt leaching, stability underground chambers*

Izračun stabilnosti podzemnih komora nastalih ispiranjem soli. Problem stabilnosti spilja vezano za namjeru njihovog sekundarnog korištenja je u tome, što je ustrojen više kao zadatak riješiti stabilnost podzemnih otvora kod kojih dolazi do lomljenja okolnih stijena kad se prekorači granica vlačne čvrstoće uslijed sekundarnih naprezanja.

Ključne riječi: *mehanika stijena, kopanje soli, ispiranje soli, stabilnost podzemnih komora*

INTRODUCTION

Under the chamber's stability is understood its static and spatial safeguarding (non-breaking) as the matter of fact in original contours after leaching out, with its perfect insulation from the surrounding rock environment with the help of antechambers, roof, and floor pillars [1]. The most dangerous state from the stability point of view that is to be investigated at the mathematical modeling, is the state when on the perimeter (in the roof, floor, or sides) of an underground opening of proposed dimensions tensile stresses begin to develop.

By controlled leaching advance and simultaneous forming caverns there starts disturbing of the primary stress state in the rock masses and at the same time the new, so called secondary stress state starts to develop. In this case it is the real stress state around an underground opening - cavern that effects the total stability of the opening in the moment of its forming. The corresponding deformation of the formed space will gradually change with the time depending on surrounding rock environment properties.

Finding out velocities and distributions of primary and following secondary stresses, around opening formed in particular conditions of rock masses belongs from the point of view of solving stability problems among decisive analytical procedures. At the same time, however, it is to mention that values of primary stresses in the rock masses are effected by several substantial factors (e.g. residual stresses in the massif where often occurs diminishing values of the vertical stress σ_z due to denudation of surface at safeguarding the original value of the horizontal stress σ_x; or substantial anisotropy or heterogeneity of rocks and complicated structural-tectonic characteristic of the massif), which require their investigation and determining the measure of influence by direct *in situ* measurements, [2].

In general it can be summarized that the construction of stable underground caverns from the point of view of required or expected shape, size, and distance of their axes, depends on the state and quality of the rock masses, [3, 4].

THEORETICAL ASSUMPTIONS

At solving the stability problems it is necessary to come out from the above given statement and following theoretical assumptions:

1. In case of homogeneous rock masses (ideal salt) the primary stresses can be characterized as isotropic. i.e.:

$$\sigma_z = \sigma_x = \sigma_y = \sigma \tag{1}$$

From this follows that the ratio between horizontal and vertical stresses is constant and equals one. Thus the lateral stress coefficient $k = 1$ and the Poisson's number $\nu = 0{,}5$ (plastic material).

2. If the values of primary stresses are different (quasi-homogeneous rock masses), but at the same time holds true that:

J. Ďurove, M. Maras, P. Vavrek, J. Daňko, BERG Faculty, Technical University of Košice, Košice, Slovakia

$$\sigma_z \neq \sigma_x = \sigma_y \qquad (2)$$

in such a case it is necessary to discern two states of stresses:

a) lateral stress is higher than vertical

$$\frac{\sigma_x}{\sigma_z} > 1 \qquad (3)$$

or $k > 1$,

b) lateral stress is lower than vertical

$$\frac{\sigma_x}{\sigma_z} < 1 \qquad (4)$$

or k is from the interval $\langle 0,\ 1 \rangle$.

With regard to the fact that all three cases are to be investigated there was done a parametric judgment that will first of all be analyzed generally from the point of view of the solved problem.

From the point of view of better utilization of the space the most suitable are rectangular shapes (prism, cylinder). The disadvantage of these shapes is, however, unfavorable secondary state of stresses in their surrounding (in the roof and in the floor). In corners of rectangular cross-sections high concentration of stresses occur, the value of which depends on the radius of rounding the corners. From the analyses of individual shapes of mine openings there follows that the most suitable are elliptical or arched ones in which do not occur high concentrations of stresses in points of their perimeter [5]. Also practical experience from underground mine openings show that there exist natural rounding of rectangular shapes until the value of stresses is decreased under the value of the rock's strength. The less the underground opening is supported, the more the natural regulation of the shape is to be respected.

CALCULATION OF MAXIMUM PRINCIPAL STRESS FOR THE ELLIPTICAL SHAPE

In the transition between rectangular and elliptical shapes there are various oval and arched cross-sections composed of various geometrical parts of ellipses. That is why in this part we have specifically aimed at the parametric judging of the stress state around the elliptical cross-section at various ratios of semi-axes of ellipses, $a : b$ (a - horizontal, b - vertical semi-axis of the ellipse).

The whole partial task was defined as follows: to judge tangential stresses in the roof and floor of the elliptical cross-section at various conditions characterizing the primary state of stresses, expressed by the ratio k (coefficient of lateral stress of rocks).

$$\frac{\sigma_x}{\sigma_z} = k \qquad (5)$$

depending on the span of the roof or floor.

This procedure comes out from analyses where it is stated that the tangential stresses on the perimeter of elliptical cross-section at given values of primary state of stresses σ_z and σ_x can be effected by the selection of the semi-axes' ratio [5]. For example the stresses in the roof and floor will always be compressed ones if:

$$\sigma_{\tan} = \sigma_x \left(1 + \frac{2b}{a}\right) - \sigma_z > 0 \qquad (6)$$

In our case the position of the investigated point on the perimeter was determined by its polar co-ordinate $w = 90°$ or 270 °. For the values of stresses in this point there was used the form with the help of the coefficient of the tangential stresses concentration n. It is the common relative form of the tangential stress $\sigma_{\tan}$ according to the value of vertical primary stress σ_z:

$$n = \frac{\sigma_{\tan}}{\sigma_z} \qquad (7)$$

ANALYSIS OF DEVELOPING DANGEROUS TENSILE STRESSES

The parametrical investigation was carried out for the following ratios of semi-axes b:a = 2,0; 1,5; 0,75 and 0,5. In Figure 1. the investigated shapes of caverns for the considered underground spaces are schematically illustrated.

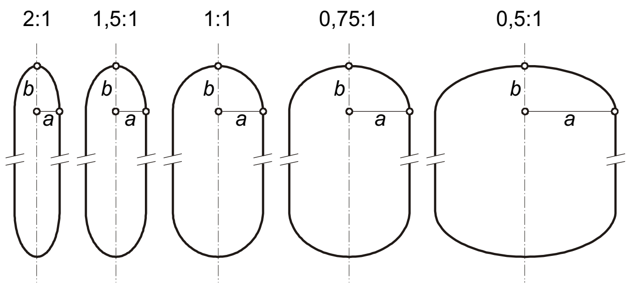

Figure 1. **Ideal shape of caverns at various ratios of semi-axes of ellipse *b:a* (*b* = 20 m)**

Slika 1. **Idealni oblik spilja s raznim omjerima poluosi elipse *b:a* (*b* = 20 m)**

For the calculation of the coefficient of tangential stresses concentration n the following values of the ratio of primary stresses k and the span of caverns (the span of caverns is considered to be the value of $2a$) were considered Table 1.

Table 1. **Values of *n***
Tablica 1. **Vrijednosti od *n***

k	*a* / m				
	10,0	13,3	20,0	26,7	40,0
0,00	–1,0	–1,0	–1,0	–1,0	–1,0
0,20	0,0	–0,2	–0,4	–0,5	–0,6
0,40	1,0	0,6	0,2	0,0	0,2
0,50	1,5	1,0	0,5	0,3	0,0
0,66	2,3	1,6	1,0	1,5	1,0
1,00	4,0	3,0	2,0	1,5	1,0
1,50	6,5	5,0	3,5	2,8	2,0

On the basis of calculated values *n* the graphs in Figure 2. were constructed. In Figure 2. the change of tangential stresses in the highest point of the elliptical cavern's roof at the change of its dimensions (in the sense of Figure 1.) and at various ratios of primary stresses is illustrated. E.g., if the horizontal to vertical stresses ratio will be less than 0.4, in the roof there will occur tensile stresses at the span higher than 53,4 m ($a \times 2 = 26.7 \times 2 = 53{,}4$ m).

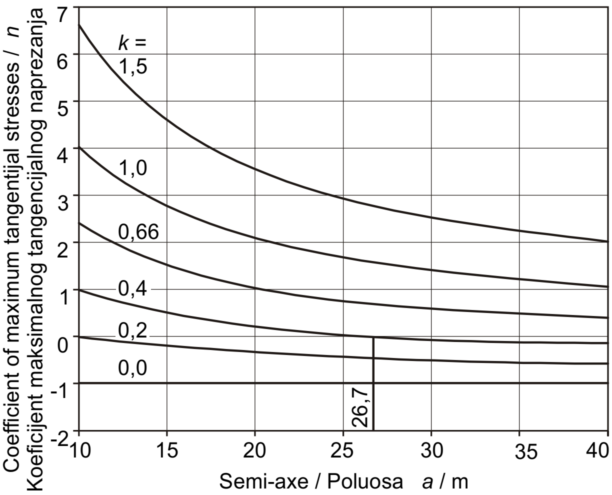

Figure 2. **Dependence of the coefficient of maximum tangential stresses concentration in the roof of elliptical cross-section σ_{tan}/σ_z, at various character of primary state of stresses expressed by the coefficient *k*, on various value of the semi-axes *a*, (i.e. half span of the cavern)**
Slika 2. **Ovisnost koeficijenta maksimalnog tangencijalnog naprezanja u svodu eliptičnog presjeka σ_{tan}/σ_z pri različitim svojstvima primarnog stanja naprezanja izraženih koeficijentom *k* na različitim vrijednostima poluosi *a* (tj. pola raspona spilje)**

From the similar calculation carried out for $w = 0$ ° (or 180 °) it follows that in the sides of the opening at the above considered *k* there will always be positive values of tangential stresses. However, in cases when horizontal stresses exceed the double values of the primary vertical stress ($k > 2$), zones of tensile stresses start to develop in points of the contact roof - side of the cavern, which can cause breaking the rock by the tensile cracks. The breaking occurs when the tangential stress is higher than the tensile strength of the rock. For the cylindrical shape of the cavern it means that its rounding in the roof and floor area forms more favorable conditions from the stability point of view. At the same time by we can forming the different shape in the roof and floor ellipse of the cavern exclude unfavorable increased concentration of stresses caused by the different depth of the roof and the floor.

By the given procedure there can be acquired a good reference basis for evaluating what underground openings and their parts (roof, sides, floor) will be connected with undesirable tensile stresses and then with the stability problems.

CONCLUSIONS

The carried out calculations and parametrical judging in this way defined different homogeneity of the massif show that the maximum principal stresses for three investigated cases will be of the compression character (*n* is of positive values):

1. at any span of the cavern (but if $a > 40$ m, the *n* decrease under 1).
2. a) at any span of the cavern (always holds true $n > 1$),
   b) if the half span of the chamber $a < 40$ m (and at the same time we suppose that $k > 0{,}5$).

By such a procedure, with the help of judging individual parameters, good starting basis can be acquired for the mathematical modeling and the following particular stability calculations and proposals for designing chambers' parameters.

Also on the results of the parametric judging the known fact that shapes and sizes of chambers will depend on the actual quality of the rock environment, [6] is confirmed.

REFERENCES

[1] J. Ďurove, M. Maras, P. Vavrek, J. Daňko: Formulation of criteria for construction of mathematical model for solving the stability of leaching chambers of the Zbudza deposit on the basis of results of geological investigation and geomechanical tests of rocks of deposit and surrounding rocks. KDLaG, Faculty BERG, TU of Košice, 1999. (Original in Slovak).
[2] B. Pandula: Určovanie porušenosti hornín sezmickými a seizmoakustickými metódami a ich aplikácia pri rozpojovaní hornín výbuchom. PhD Thesis, BERG Faculty, the Technical University of Košice, 1995.
[3] A. Mockovčiakova, B. Pandula: Study of the relation between the static and dynamic modulus of rocks, Metalurgija 42 (2003) 1, 37 - 39.
[4] B. Pandula et al.: The influence of rocks on the dynamic characteristic of elastic waves. Acta Montana ÚG ČSAV 84 (1992), 207 - 214.
[5] J. Hatala, P. Trančík: Mechanics of rocks and rock masses. ALFA Bratislava, 1982. (Original in Slovak).
[6] Plan of the exploitation of leaching fields No 1. and No 2. (Proposal of the documentation to the application for approving the mining activity), Solivary, a.s. Prešov, January 1998. (Original in Slovak).