Simulation of rock failure over cylindrical chamber

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Abstract

Numerical simulation is performed for the changes of stress field at consecutive extraction of diamond ore deposit. The features of stress distribution around openings are examined. Failure zones of rock mass are determined. The results of calculations were compared with the experimental data of observations *in situ.* Geomechanical recommendations are proposed for placing of technological workings.
Keywords: diamond pipe, cylindrical chamber, stress state of rock mass, finite element method, elastic model, axisymmetric problem, Coulomb-Mohr criterion, failure zones, fracture.

1 Introduction

Open-pit mining method is used for excavation of ore at Siberian diamond deposits. The maximum depths of open-pits are reached. Last years the deep mining is applied. One of the diamond pipes is mined at a depth of 800 m. As a result some cylindrical mined out spaces with a diameter 60 m and a height 10-70 m were filled with the solidifying fillings. Under these conditions a number of geomechanical problems arises. The main of them is the possible rock fall into workings. The experience of application of geomechanical investigations in practice is discussed. Character of failure in undermined rock mass was researched. Strength of rock has a wide rage of values. The difference in mechanical properties sets a limit of accuracy of analysis. The finite element method was used for forecasting the stress state of rock mass near the chambers during development of mining works.

2 Finite element model

The results of experimental investigations showed the initial principal horizontal stresses are approximately equal to 0.7-0.8 of vertical pressure been due to a weight of overlying rock thickness at the depth [1]. Therefore the numerical solutions of axisymmetrical problems may be used. The initial stress state of rock mass is following

$$\sigma_z^0 = \gamma z,\ \sigma_r^0 = \sigma_\Theta^0 = \frac{\nu}{1-\nu}\gamma(z-H) + \lambda\gamma z,\ \tau_{rz}^0 = 0$$

where z is a distance from the surface of the earth, γ is specific gravity of rock (27 KN/m^3), λ - ratio of initial horizontal stress to vertical one (0.75) at the depth H (800 m), ν is Poison's ratio of rock (0.25). The problems were solved in terms additional displacements [2] under the following boundary conditions on the external boundary (the surface of the cylinder with a diameter 4 km and a height 2 km): the upper horizontal boundary is free from stresses, additional displacements are equal to zero on the lower horizontal boundary, additional horizontal displacements and tangential stresses are equal to zero on the vertical boundary. Elastic modulus of rock was taken equal to 20 GPa. The heights of mined-out spaces (cylinders with the diameters 60 m) are quoted on the corresponding illustrations of problems. Elastic modulus of artificial fillings is less than 1GP. Reaction of filling massif, been due to displacements of contour of mined-out space with the height about 100 m, is not in excess of 1-2 MPa. Stresses of rock are approximately equal to 20 MPa on the depth. Fillings creates small pressure, which prevents the rock fall into workings. The filling massif did not come into account in the modelling.

In the case of axisymmetric problems with elements in form of ring with triangular cross section the element contribute to stiffness matrix is defined as

$$k_{ps}^e = \frac{\pi\bar{r}}{2|\Delta|}\mu \begin{vmatrix} b_p b_s + c_p c_s + \alpha(b_p d_s + d_p b_s) + \beta c_p c_s & \alpha(b_p + d_p)c_s + \beta c_p b_s \\ \alpha c_p(b_s + d_s) + \beta b_p c_s & c_p c_s + \beta b_p b_s \end{vmatrix},$$

where parameters are determined as follows

$$\alpha = \frac{\nu}{1-\nu},\ \beta = \frac{1-2\nu}{2(1-\nu)},\ \mu = \frac{E(1-\nu)}{(1+\nu)(1-2\nu)}$$

(E is Young's modulus of rock) [3]. Matrix k_{ps}^e characterises the dependence of the displacements (u_r, v_θ) of neighbouring nodes with numbers p and s. The geometrical parameters b, c, d are defined with co-ordinates of nodes of the element [4]

$$b_p = z_s - z_q,\ b_s = z_q - z_p,\ c_p = r_q - r_s,\ c_s = r_p - r_q,$$

$$d_p = \frac{r_q z_s - r_s z_q}{\bar{r}} + b_p + \frac{c_p \bar{z}}{\bar{r}},\ d_s = \frac{r_p z_q - r_q z_p}{\bar{r}} + b_s + \frac{c_s \bar{z}}{\bar{r}},$$

($\bar{r}, \bar{z}$ are co-ordinates of the centre of triangular cross section of the element with nodes p,q,s). The absolute value

$$\Delta = 1/2\,[(r_q - r_s)(z_p - z_s) - (z_q - z_s)(r_p - r_s)]$$

is equal to the area of the triangle. The components of nodal forces

$$R_p^e = sign(\Delta)\pi\bar{r}(b_p\sigma_r^0 + d_p\sigma_\Theta^0 + c_p\tau_{rz}^0),$$
$$Z_p^e = sign(\Delta)\pi\bar{r}(c_p\sigma_z^0 + b_p\tau_{rz}^0)$$

take into account the initial stresses σ_{ij}^{0} in the element [5]. The nodal forces are not equal to zero on the internal boundaries of the domain. A system of linear equations for nodal displacements was solved with the successive over-relaxation method [6].

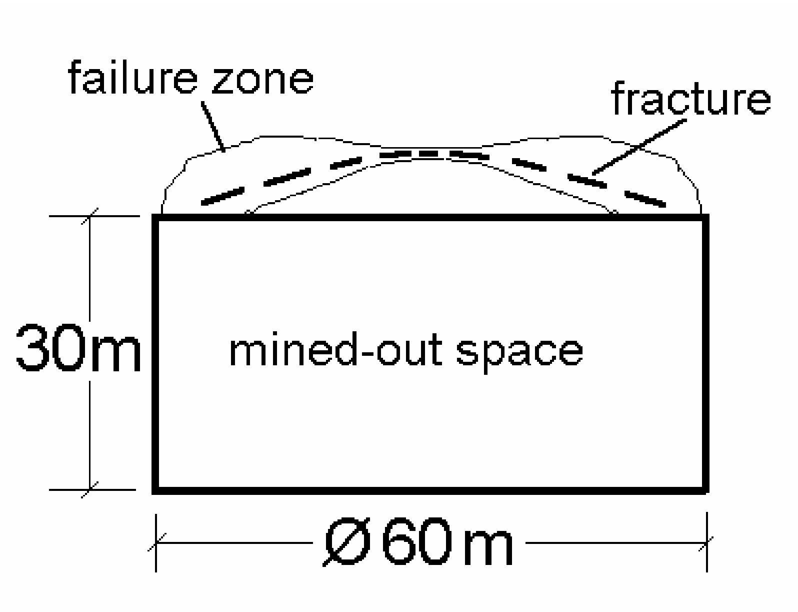

Figure 1. Failure zone above the mined-out space.

3 Results of calculations

The calculated safety factor

$$f = \frac{2c\cos\varphi + (\sigma_{max} + \sigma_{min})\sin\varphi}{\sigma_{max} - \sigma_{min}}$$

was used for analysis of rock massif's failure, where σ_{max} and σ_{min} are the largest and smallest principal stresses, found from the elastic solution. C and φ are the parameters of the rectilinear envelope of the limiting Mohr circles (cohesion and angle of internal friction) [7]. The safety factor becomes equal to 1, when the Mohr circle is tangent to the envelope. The following term has been accepted in the paper. The failure zone is the area, where the safety factor is less than 1 for the supercritical stress state. The figure 1 illustrates a calculated failure zone of undermined ore rock massif and a real fracture of technogenic, which was discovered with practical visual observations of the state of workings (C is equal to 3.2 MPa and φ is equal to 30^0). The computer modelling let to determine the form and the sizes of rock failure zones and to estimate a position of fracture in undermined ore rock massif. The figure 2 illustrates failure zones of country rock (C is equal to 5 MPa, φ is equal to 30^0 and the height of the mined-out space is approximately equal to 140 m). The technological workings are necessary for filling mined-out space in with the solidifying fillings. In the case, when the technological workings are on the distance 5 m from the boundary of the pipe (the left side of the fig.2), the failure zones are larger than in the case of distance 10m (the right side of the fig.2). The carried out geomechanical analysis let to recommend the distance 10m between the technological workings and the contour of the ore body.

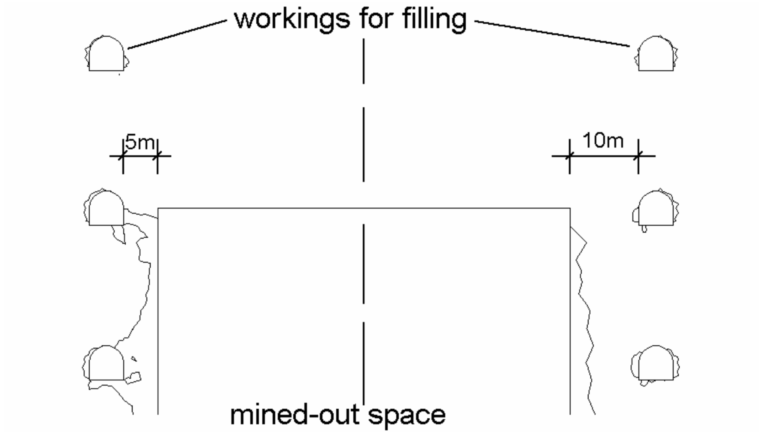

Figure 2. Failure zones of country rock.

4 Conclusion

The axisymmetric elastic model can not describe all peculiarities in deformation of rock massif near cylindrical mined-out spaces, but it allows to estimate sizes and limits of failure zones around workings. The proposed approach may be used for geomechanical analysis of state of rock mass near cylindrical mined-out spaces, which have been created during extraction of diamond ore deposits.

References

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