UDC 622.549.514.51

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INNOVATIVE APPROACHES TO ROCK MASS STABILITY IN MINING HIGH-GRADE QUARTZ VEINS*

In mining high-grade quartz veins, it is strictly required to produce pure quartz concentrate and to reduce loss and dilution of the useful mineral component. Compliance with the requirements, in accordance with the specifics of quartz production, is in many ways dependent on stability of mine openings. It is known that mine support pressure mainly grows due to displacement of wall rocks toward the axis of a mine opening (convergence) in the course of the working face advance. The results of numerous studies into the mechanism of this process in an elastic rock mass allow optimizing stability of mine openings. On the other hand, the mentioned process in a post-limiting stress state rock mass yet remains to be studied. This article describes findings of investigation of support pressure in the working face area in the post-limiting state rock mass. The investigations involved in situ measurements of rock deformation in the face areas with the spacings conformable with the cross-section dimension of an opening in terms of drivage a mine shaft using a combination technology in a hard rock mass in the post-limiting stress state. Based on the accomplished measurements and using FSP-1 Trends program to construct nonlinear regression equations and function–factor trends, the mathematical model describes the change in the absolute deformation of wall rocks in the course of the working face advance. The mathematical model produces an exponential dependence of the convergence factor α and the ratio between the distance to the face, L, and the radius of the mine opening, R. The values of the factor α* determined in the post-limiting stress rock mass differ significantly from the same factor values obtained earlier for the elastically deforming rocks. The comparative analysis of the changes in α* in the host rock mass of Kyshtym quartz deposit subject to elastic deformation and in the rock mass in the post-limiting stress state shows significant difference between the two processes, which is to be accounted for when selecting support design and installation procedure.*

Key words: *deformation, country rock mass, ultimate strength, post-limiting state, drivage of mine openings, work face advance, convergence, displacement, dependence.*
DOI: *dx.doi.org/10.17580/em.2016.02.01*

Introduction

An increase in support pressure and subsequent damage of the support and instability of surrounding rock mass develop under mining-induced deformation of wall rocks. Drivage and, especially, shafting cause relaxation of enclosing rocks, which is accompanied by displacement of wall rocks toward the axis of a mine opening (convergence) [1, 2]. The zone of deformation of enclosing rocks in the course of making a vertical shaft (as in the present experimental investigation) begins ahead of the shaft bottom and embraces the bottom area of the shaft [3, 4]. The shaft bottom restrains full-degree displacement of wall rocks in the near-bottom zone [5, 6]. The shafting process induces displacement of rocks in the shaft walls towards the shaft axis, U. Deformation of shaft wall rocks gradually grows as the shaft is advanced.

Main part

Displacement of elastic surrounding rock mass in the course of advance of a shaft bottom is accounted for by an introduced corrective and reductive factor α^*, which is a quantity of unrealized deformation as the shaft is advanced [7, 8]:

$$U = U_\infty(1 - \alpha^*), \tag{1}$$

where α^* is given by:

$$\alpha^* = A\cdot\exp(\beta\cdot L/R). \tag{2}$$

The overall displacement U_∞ is realized in the wall rocks at a distance of 3 shaft radii from the shaft bottom (**Fig. 1**) [6].

Convergence of wall rock walls in a working face area in the course of the face advance was studied by such researchers as M. Baudendistel, B. Amusin, N. Bulychev, A. Zubkov, A. Balek.

Using the finite element method, Baudendistel obtained a load factor α^* [7]:

$$\alpha^* = 0.64\exp(-1.75L/R). \tag{3}$$

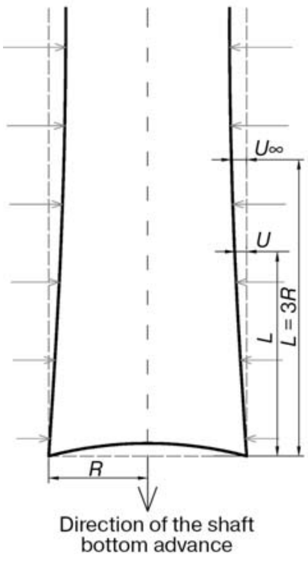

Fig. 1. Displacement of shaft wall rocks at the bottom when *A* = 1: *L* — distance between the observation point and the shaft bottom; *R* — approximate radius of the shaft; *U* — deformation of the shaft wall rocks, *U*∞ — overall deformation of the shaft wall rocks

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*Work is executed at financial support of the Ministry of education and science of the Russian Federation (project RFMEF160714X0026)

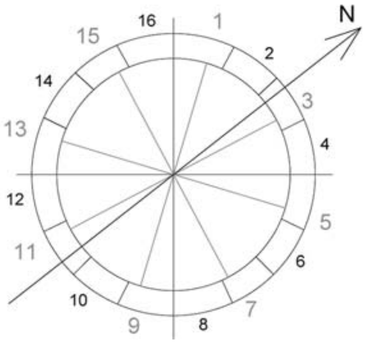

Fig. 3. Layout of measurement plugs in the Cage Shaft

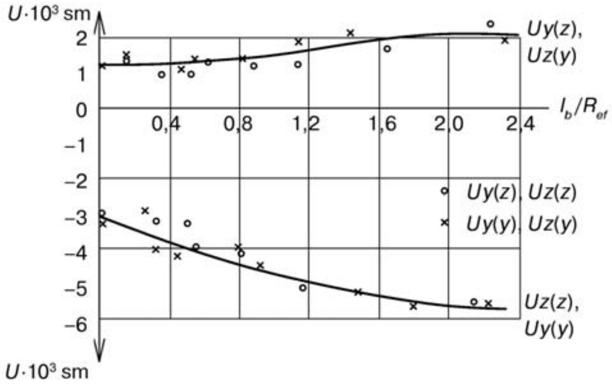

Fig. 2. Radial deformation of sidewalls in a circular underground excavation (according to A. Zubkov)

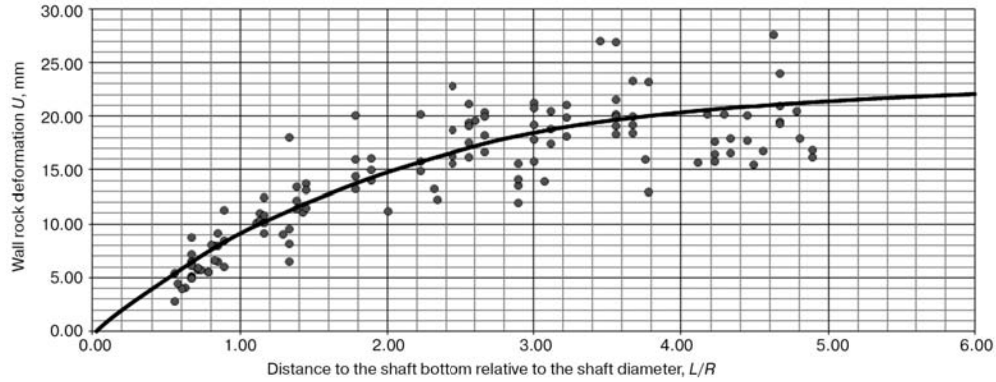

Fig. 4. The plot of the displacements *U* in the shaft wall rocks versus the ratio between the distance to the shaft bottom, *L*, and the approximate shaft radius *R*

Amusin, based on the processed data of in situ monitoring of rock mass displacements in underground excavations, offered another empirical formula to calculate the discussed factor [7]:

$$\alpha^* = \exp(-1.3L/R). \quad (4)$$

Bulychev also greatly contributed to the research into the influence exerted by drivage on stress state of surrounding rock mass and derived an exponential dependence based on the correlation analysis by Baudendistel [7]:

$$\alpha^* = 0.6\exp(-1.38L/R). \quad (5)$$

Zubkov undertook comprehensive studies into the influence of the working face advance on the stress state of enclosing rock mass using 3D simulation on foamed plastic material [9]. As a result, deformation of wall rocks around a circular cross-section excavation during working face advance was determined (**Fig. 2**). The trend lines of tension (upper line) and compression (lower line) flatten at $L/R = 2$, i.e. the influence zone of an excavation is equal to two radii of the excavation.

The Institute of Mining, UB RAS, accomplished the research into convergence and stress state of rock mass and pressure exerted on shaft lining under conditions of elastic deformation of rocks in the course of mine shafting at Don Mining and Processing Plant. As a result, the exponential dependence given below was obtained [5]:

$$\alpha^* = 0{,}55\exp(-1{,}75L/R). \quad (6)$$

The research and calculation of α^* were carried out on an elastic model of intact rock mass subject to gravitational and tectonic stresses not higher than ultimate strength of rocks. Such ground conditions are common in the territory of the Urals. In particular, at the quartz deposit developed by Kyshtym Mining and Processing Plant, the jointed enclosing rock mass deforms as in elastic uniform model. This is conditioned by good cohesion of rocks composing surface of joints and by comparatively low tectonic stresses, round 2–4 MPa.

Rocks in post-limiting stress state, when tectonic stresses exceed ultimate strength of rocks, deform differently. Rock mass disintegrates and rock blocks mutually displace and slide along their interfaces. The destructure and the post-limiting stress state change the regular pattern of convergence and induce related alteration of the factor α^* [10].

In the Cage Shaft in Tsentralnaya Mine, Don Mining and Processing Plant, convergence of wall rocks was investigated in serpentinite rock mass. At the depth of 500 m below ground surface, the rocks experienced post-limiting stress state. Under the post-limit stress, higher rate displacement of rock blocks took place, which led to step-by-step deformation [11, 12].

Deformation of the wall rocks was measured at the depth of 800–830 m, in tubbing rings nos. 348, 350, 354, 357, 360, 363 and 365 in the Cage Shaft being driven using a combination technology. The measurements were taken at large spacings of plugs installed in enclosing rock mass through backfill holes 1 m long in the tubbing rings. The spacing of these plugs was measured in four directions between tubbings nos. 1–9, 3–11, 5–13 and 7–15, along diameters arranged at 45°, as the shaft bottom was advanced from the installation points of the plugs (**Fig. 3**) [13].

The results of the in situ tests are depicted in **Fig. 4**. Each point stands for the measurement of rock mass deformation at different distances between the measurement plug and the shaft bottom.

Using the test results and FSP-1 Trends program to construct nonlinear regression equations of functions and factors [14], the relation presented below has been produced (at the coefficient of determination $R_2 = 0{,}80$):

$$U = 24(1 - \exp(-0.48L/R)). \quad (7)$$

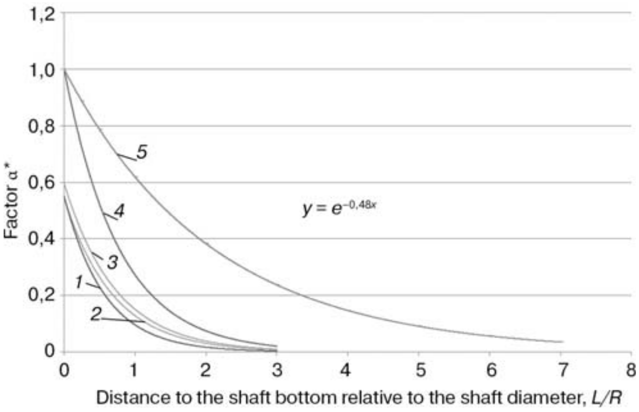

Fig. 5. Relationship between *x* = α* and the ratio of lining-and-shaft bottom spacing to the approximate radius of the shaft, *y* = *L*/*R*: *1* — by Institute of Mining UB RAS; *2* — by Baudendistel; *3* — by Bulychev; *4* — by Amusin; *5* — Post-limiting state rock mass

The plot illustrates the change in the deformation *U* as the distance to the shaft bottom grows. An increase in *U* is gradual, 70% of deformation realizes when the distance to the shaft bottom is equal to two radii of the shaft. The plot flattens at U_∞=24 mm, which implies full realization of deformation when the distance to the shaft bottom makes 7–8 approximate radii of the shaft.

From the mathematical model of deformation (7), the exponential relation between the factor α* and the ratio between the distance to the shaft bottom and the approximate shaft radius is given by:

$$\alpha^* = \exp(-0{,}48L/R). \qquad (8)$$

Values of the factor α* obtained in rocks in the post-limiting stress state considerably differ from this factor evaluated earlier for the elastically deforming rock mass. **Fig. 5** illustrates the comparison of the earlier and present test results. It is seen in the figure that the wellbore bottom zone in case discussed in this article is 2–2,5 times larger than in rocks under elastic deformation and makes 7–8 approximate radii of the wellbore.

Conclusion

Thus, the values of the factor α*, that defines rock pressure and stability in an underground excavation, and the behavior of this factor are different in the elastic and posit-limiting state rocks, so, it is impossible to use the same value of α* for all types of rock masses.

In order to maintain stability of excavations in mining high-grade quartz veins, it is required to select a support design and installation procedure in accordance with the advance of a work face based on the regularities of variation in the factor α* in compliance with the elastic or post-limiting stress state of rock mass.

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