The Influence of Time-Varying Stresses in the Rock Mass on the Stress State of Mine Workings

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Abstract. The stress state of the concrete walling of mine shafts is formed as a function of the structural parameters of the shaft, the total stress tensor, which includes gravitational-tectonic and time-varying stresses acting in the rock mass at the baseline, taking into account the physical and mechanical properties of the rock mass, the elastic modulus of concrete, which depends on the rate of advance and additional stresses caused by a subsequent change in the stress field, determined outside the zone of influence of mining by a cyclic change in natural stresses, and in the zone of influence of the mined-out space - by a change in the secondary stress field. The paper has presented the results of the research, which significantly increase the degree of geomechanical study of the Gaiskoye deposit's rock mass. The main purpose of the research was to determine the parameters of the initial stresses acting in the concrete walling of the shafts at different depths. The parameters of stresses acting in the shaft walling at deep mine horizons were determined under field conditions, and the stress-deformed state of the shaft walling at various horizons was monitored throughout the depth of the shaft in the period 2013 - 2020.

1. Introduction

The Gaiskoye copper-pyrite deposit has been operated since 1959 and is represented by deposits of complex lenticular and vein-like forms: copper pyrite, copper-zinc pyrite, sulfur pyrite and vein-disseminated ores. The host strata is represented by albitophyres, tufaceuccia and tuffs [1].

The shafts are in tufts of andesitodacite composition having elastic modulus in rock sample $E_0 = 0.72 \cdot 10^5$ MPa. The modulus of elasticity in the rock mass is determined by the following formula [2]:

$$E_m = 0.93^n \cdot E_u, \text{ MPa}$$

where $E_u$ is the modulus of elasticity of the rock sample;

$n$ is the number of ranks of geoblocks.

When determining the natural time-varying stresses $\sigma_{A\Phi}$, the authors measured the deformation of bases with lengths of 40-50 meters. In the rock masses with the average size of structural blocks of 0.5 meters and the inclusion coefficient $\lambda = 2$ the modulus of elasticity of the rock mass $E_u$ on these bases at $n = 5$ will make:

$$E_u = 0.93^n \cdot 0.72 \cdot 10^5 = 0.5 \cdot 10^5 \text{ MPa}$$
In order to increase the productivity of the Gaiskiy underground mine from 5.6 to 9 million tonnes of ore per year, a development project entitled "Development and mining of deep horizons in the -830...-1310 m underground mine floor" has been created. The project addresses the issues of development and mining of deep horizons of the underground mine, development of new ore delivery schemes, reconstruction of the mine shafts and their sinking down to -1420 m from the surface. Since 2012 the priority objects are the mines Exploitation, Cageway, New and Northern Ventilation (Fig. 1) [2].

2. Relevance, scientific significance of the issue with a brief review of the literature

Human work (economic activity) in underground conditions is associated with the construction of underground structures of varying complexity, whose elements stability should be calculated to ensure safety. The boundary conditions for such calculations are physical and mechanical properties of the rock mass and its stress-deformed state (SDS).

Taking into account the complexity and quantity of the work to determine the SDS of the rock mass in underground conditions, the authors performed usually one series of measurements at the mines at a specific time and at a specific depth and used these results at a later stage, considering the tectonic component ($\sigma_T$) as a constant. At a number of the mines, the authors performed two, three, and more series of measurements while new horizons were developed [3]. This made it possible to trace the change in stresses with depth, and it was possible to analyze the change in these results over time [4].

3. Statement of work, theoretical part, practical experiment

Since 2013, the stress-deformed state of the shaft walling has been monitored at the Gaiskiy underground mine. At this stage of the research, the changes in stresses acting in the shaft walling of the Cageway mine were determined at the deposit. The measurements were made on bases of different lengths and different horizons [5].

The stations are installed in the travelling way of the Cageway mine shaft, at -830 m, -910 m, -990 m, -1070 m and -1390 m marks.
The authors have measured the active stresses in the shaft walling at the locations of the stations using the slot unloading method [6]. Subsequently, these bases are used to measure changes in the stress-deformed state over time [3] at intervals of three to four months.

The additional stations have been installed at the same selected sites for measuring the deformations at the base of 1600 mm and for recording the horizontal and vertical deformations of the walling.

Based on the results of measurements with the new slot method [7]. By solving the plane elasticity theory problem, the authors recalculate the obtained values of relative deformations to the stresses by formula (1) and present the results in Table 1:

$$\sigma = \frac{U_{AB}E_b}{1,034*2L\left(1 - K_{\perp(\perp)} + \mu K_{\parallel(\perp)}\right)}$$

where $U_{AB}$ is the offset value of the benchmarks at the AB base, cm; $E_b$ is the elastic modulus of concrete, MPa; $l$ is the distance between the benchmarks, m; $L$ is the slot radius, m;

Table 1. Results of the calculation of stresses in the shaft concrete walling by the slot unloading method.

| Station | 1st station (horizon -830 m) | 2nd station (horizon -910 m) | 3rd station (horizon -990 m) | 4th station (horizon -1075 m) | 5th station (horizon -1390 m) | 6th station (horizon -1390 m) |
|---------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Stresses | -2.9 MPa                    | -2.9 MPa                    | -0.72 MPa                   | -1.4 MPa                    | -0.72 MPa                   | -1.4 MPa                    |

The received values of stresses in the walling built at the combined sinking method differ from theoretical values at the expense of that the concrete has not gained the full durability and has been deformed plastically.

4. Research results
As a result of the monitoring data analysis of the stress-deformed state in the Cageway shaft walling, shown in Fig. 2-4, the change of the stress-deformed state towards the compression increase was recorded for all horizons, down to -12 MPa for the lower horizons in the horizontal (X) direction, and down to -9 MPa for the vertical (Z) direction.

Figure 2. Diagram of stress changes in the concrete walling of the Kletievaya mine shaft at the horizon -830 m.
Fig. 3. Diagram of stress changes in the concrete walling of the Cageway mine shaft at the horizon - 910 m.

Fig. 4. Diagram of stress changes in the concrete walling of the Cageway mine shaft at the horizon - 990 m.

The diagrams shown in Fig. 2-4 are consistent with the results of the measurements of the time-varying stresses in the rock mass, being performed by the Laboratory of geodynamics and rock pressure since 2001 throughout the series of the measurements of stresses acting in the rock mass. The measurements were performed by the flexible thread method [8] at the bases down to 50 m at the stations installed in the workings of the shaft inset of the horizon -830 m.

5. Conclusions
For decades, there has been a coincidence in time of extremes of cosmic ray intensity, solar radiation energy and astrophysical characteristics of the stress-deformed state of the Earth's crust, which suggests a unified nature of the physical processes that caused them in the cosmos.

The received results given in the published papers [10-15] suggest the research directions, and it is necessary to carry out them on a wide scale since the change in the Earth sizes and the accompanying change of the stress-deformed state of the rock mass (of the Earth crust) by the value $\sigma_{AF}$ is the reason of natural and technogenic disasters.

Thus the shaft exploitation process forms the stress state of the concrete walling as a sum of known [1] measured $\sigma_{kp}^{ISM}$ and additional $\Delta\sigma_{kp}$ stresses caused by the subsequent change of the stress field.
determined outside the zone of influence of mining operations by time-varying component, and in the zone of influence of worked out space by changing the secondary stress field.

The diagrams presented in Fig. 1, 2 and 3 agree with the results of measurements of the time-varying stresses [4] in the rock mass, being performed by the Laboratory of geodynamics and rock pressure at the Gaiskiy underground mine since 2001. Measurements were performed by the flexible thread method at the bases down to 50 m at the stations installed in the workings of the shaft inset. The difference in stress values is explained by the different modulus of rocks and the concentration of stresses in the peripheral part of the shaft. Fig. 4 shows the diagram of changes in the time-varying stresses since 1998 at the Ural mines against the background of changes in the solar radiation power ($S_0$) and the cosmic ray intensity [4].

![Graph showing Cosmic rays variations, $S_0 / Wm^{-2}$, $\varepsilon_{\Delta \Phi}$ and $\sigma_{\Delta \Phi}$](image)

**Figure 5.** Change in the SDS parameters ($\varepsilon_{\Delta \Phi}$ and $\sigma_{\Delta \Phi}$) based on averaged annual data at the Ural mines against the background of changes in the solar radiation power ($S_0$) and the cosmic ray intensity.

**6. Result**

When comparing the stresses obtained by experimentally analytical way in the concrete walling of mine shafts from 2013 to 2020, the experimental field test sites having the length of bases 1600 mm and 70 mm have established the relation with the results of measurements in the rock mass at the base of 50 meters. On the basis of the performed experiment it is confirmed that the theoretical and experimental studies prove that the hierarchical block mass of magmatic and metamorphic rocks behaves as an elastic and isotropic medium and the changes of natural stresses in the $\Delta \sigma_{\Phi}$ rock mass at the base of 5-7 ranks of geoblocks, on the contour of the shaft at the base of 2-3 ranks of geoblocks and in the concrete walling of mine shafts $\Delta \sigma_b$ are subject to this law.
7. References

[1] Zubkov A V, Zubkov Yu M 1999 Modulus of deformation of the rock mass - function of ranks of composing blocks” in Proceedings of International Conference on Geomechanics and stress state of the Earth's interior (Novosibirsk, Russia) pp 65-70

[2] Sentyabov S V 2018 Investigation and forecast of the change in stress-deformed state of the mine shaft walling at Gaiskiy mine Mountain Information and Analytical Bulletin 10 79

[3] Zubkov A V 2016 Principle of formation of natural stress state of the Earth's crust Lithosphere 5 146

[4] Zubkov A V 2013 Periodic expansion and contraction of the Earth as a probable mechanism of natural cataclysms Lithosphere 2 145

[5] Sentyabov S V 2015 Estimation of the combined shaft walling efficiency Mountain Information and Analytical Bulletin 6 406

[6] Sentyabov S V 2017 Monitoring of the stress-deformed state of the concrete shaft walling at Gaiskoye deposit Mining Problems 2 119

[7] Sentyabov S V 2014 Analysis of the current state of the vertical shaft construction Mountain Information and Analytical Bulletin 7 415

[8] Zubkov A V 2001 Geomechanics and geotechnology (Ural Branch of RAS, Ekaterinburg)

[9] Kozhurin A I 2014 Speed of collisional deformations of Kamchatka peninsula (Kamchatka) Geotectonics 2 42

[10] Chongyuan Zhang, Qunce Chen, Xianghui Qin, Bo Hong, Wen Meng, Quanfeng Zhang 2017 In-situ stress and fracture characterization of a candidate repository for spent nuclear fuel in Gansu, northwestern China Engineering Geology Vol 231 pp 218—229

[11] Shuai Yin, Wenlong Ding, Wen Zhou, Yuming Shan, Runcheng Xie, Chunhua Guo, Xiangyu Cao, Ruyue Wang, Xinghua Wang 2017 In situ stress field evaluation of deep marine tight sandstone oil reservoir A case study of Silurian strata in northern Tazhong area Tarim Basin NW China Marine and Petroleum Geology Vol 80 pp 49-69

[12] Cheuk Yiu Lai, Louis Ngai Yuen Wong, Mark Wallace 2019 Review and assessment of In-situ rock stress in Hong Kong for territory-wide geological domains and depth profiling Engineering Geology 248 pp 267-282

[13] Obrzud R F, Truty A 2018 The Hardening Soil model A practical guidebook

[14] Truty A, Obrzud R 2015 Improved formulation of the hardening soil model in the context of modeling the undrained behavior of cohesive soils Studia Geotechnica et Mechanica Vol 37 2 pp 61-68

[15] Wang W D, Li Q, Xu Z H 2017 Determination of parameters for hardening soil small strain model of Shanghai clay and its application in deep excavations (Seoul) pp 2065-2068

Acknowledgments

The studies have been performed within the limits of the state order No. 075-00581-19-00 (Theme No. 0405-2019- 0007).