Research of The Stress-Deformed State at the "Shikhanskoe", "Novobakalskoe", Developed by the "Siderite" Mines

S V Sentyabov¹, R V Krinitsyn¹, E M Ushakov¹

¹The Institute of Mining of the Ural Branch of RAS, Ekaterinburg, Russia

Abstract. The stress state in the structural elements of development systems is formed as a function of the design parameters of mine workings, the full stress tensor, which includes gravitational-tectonic and time-varying stresses acting in the rock mass at the time of the start of research, taking into account the physical and mechanical properties of the rock massif, modulus of elasticity and additional stresses caused by a subsequent change in the stress field, caused outside the zone of influence of mining by a cyclical change in natural stresses, and in the zone of influence of the mined-out space - by a change in the secondary stress field.

An assessment was made of the possibility of self-collapse of overlying rock masses near the workings of block No. 10, No. 20, No. 11, MBTs10-20, No. 21 in the conditions of its undermining by underground mining of horizons 540 m and 480 m of the Sideritovaya mine, and recommendations were developed to ensure production safety works.

On the basis of mining and technical documentation of the mine, field and laboratory measurements, an analysis of the mining and geological conditions of development of the investigated deposits, an analysis of the natural stresses of the deposit was carried out, the physical and mechanical properties of rocks were studied, the calculation of the stress-strain state of the rock mass at operation of the Sideritovaya mine near the mine workings of blocks No. 10, No. 20, No. 11, MBTs10-20.

An assessment was made of the current state of the stress state at the field, as well as the associated components of the natural environment, and the compliance of this state with the requirements of norms, standards and conditions for the extraction of minerals.

The current, operational forecast of changes in the stress-strain state in the field and in the zone of significant influence of its development has been compiled.

The presented results of the studies, which significantly increase the degree of geomechanical study of the rock massif of the Bakalskoe deposit. The main purpose of the research was to determine the parameters of the initial stresses acting in the rock mass.

1. Introduction

At present, BakalskoeRudoupravlenie LLC is developing the Sideritovaya mine. The Sideritovaya mine includes two deposits: Novo-Bakalskoye and Shikhanskoye. Both deposits have been developed since about the middle of the 20th century.

Inclined ore bodies of medium thickness and thick are mined. The excavation is carried out by storey-chamber and sublevel-chamber development systems. The depth of mining is 200-300 m.

The deposits have a complex geological structure and tectonic disturbance, uneven distribution of reserves in the depths, a variety of conditions for the stability of ores and host rocks.

A complex of mining-geological and mining-technical factors has a great influence on the stability and rock-burst hazard of workings and pillars: the strength properties of the enclosing rocks and ores,
the level of natural stresses, the presence of nearby openings, the accumulation of underground voids, etc. All this complicates the development of the deposit.

IGD UB RAS (IGD MCHM USSR) carried out studies of the geomechanical state of blocks No. 8 and No. 20 at the Shikhanskoye field in 1987-88. In the reports on research work, the results of field measurements of natural stresses were stated, the strength properties of the massif were clarified, the issues of determining the parameters of stable pillars and outcrops of treatment chambers were considered. However, the issues of rock bump propensity were not considered.

The release of ore from the treatment blocks is carried out either by scraper winches or self-propelled machines PDM.

From the treatment blocks the ore mass is transported by rail to the ore dumps on the mountains. +540 m, +480 m, where it flows into an underground crushing complex equipped with a jaw crusher with apron feeder. Further, the crushed ore is delivered to the DOF by a conveyor along the tilt shaft.

The release of rock from the mine is carried out by cage lifting of the shafts. "Auxiliary # 1" in trolleys from the mountains. +600 m, +540 m, +480 m.

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 [1]. 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 [2].

3. Statement of work, theoretical part, measurement technique

In 1987, specialists from the Institute of Mining of the Ural Branch of the Russian Academy of Sciences (then the Institute of Mining of the Ural Branch of the Russian Academy of Sciences) carried out field observations of the natural stress state at the mine by the method of crevice unloading according to the corresponding technique of the Institute of Mining of the MCHM USSR (IGD UB RAS) [4-6,7,8]. The measurements were carried out in blocks No. 8 and No. 20 of the Shikhanskoye field, at a horizon of +600 m. The depth of mining operations at the measurement site was 200 m.

The following components of the natural stress field of the rock massif were obtained:

- Vertical component $\sigma_w = -4$ MPa;
- Horizontal stresses acting across the strike of ore bodies $\sigma_{\pi} = -12$ MPa;
- Horizontal stresses acting along the strike of ore bodies $\sigma_{\pi\rho} = -15$ MPa.

Minus sign means rock compression.

Additionally, in order to clarify the horizontal component of the natural stress field in 1988 in block No. 8 by means of slotted unloading methods and measurements of displacements during mine drifting according to the methods of the IGD MCHM USSR (IGD UB RAS), measurements of the stress state of the rock mass were carried out [4-6,7,8]. Based on the observation results, the following components of the natural stress field of the rock mass were obtained:

Horizontal stresses acting across the strike of ore bodies $\sigma_{\pi} = -18$ MPa; along the strike $\sigma_{\pi\rho} = -12$ MPa.

Thus, according to the results of field observations in 1987-88, it was found that vertical stresses in the field are influenced by the weight of the overlying rocks. The horizontal stresses are additionally significantly influenced by the tectonics of the field. The tectonic component of horizontal stresses reaches values of 10-16 MPa.
Thus, it can be concluded that gravitational-tectonic stresses are acting on the field. It should be noted that the characteristics of the stress field in the rock mass at the field are also significantly influenced by the contour of the pit being worked on. Thus, it was found that in the near-side zone of the open-pit, the stresses acting along the normal to the side sharply decrease [5]. Naturally, the influence of opencast mining must be taken into account when assessing man-made stresses in the design parameters of mining systems in order to ensure the safety and efficiency of mining operations.

3.1. Measurement technique
The measurement of stresses in rocks was carried out according to the methodology of the IGD Ural Branch of the Russian Academy of Sciences [8, 9]. The main provisions of the methodology are given below.

The assessment of the acting stress in the element of the array was carried out by changing its stress state by driving a slot and measuring the corresponding reactions in the form of deformations of spacer benchmarks installed perpendicular to this slot (Fig. 1). The holes for the spacer benchmarks were drilled with electric drills with a depth of no more than 50 mm and a diameter of 10 mm. The design of the unloading slot was carried out by sawing with a gas saw with a diamond disc with a diameter of 350 mm. To measure stresses, sections are selected in two mutually perpendicular workings with a monolithic structure (Fig. 2).

**Figure 1.** Scheme for measuring deformations during unloading by a slot.

**Figure 2.** Dischargeslots layout.
As a rule, stresses acting along the strike of the ore body $\sigma_{\parallel k}$ (vertical discharge slots) and vertical $\sigma_{Zk}$ (horizontal discharge slots) are measured on the crosscut (ort), where $k$ is the number measuring points. On the roadway, the stresses acting across the strike of the ore body $\sigma_{\perp k}$ (vertical discharge slots) and vertical $\sigma_{Zk}$ (horizontal discharge slots) are measured (Fig. 3).

![Figure 3. Scheme for voltage measurement by the method of slotted unloading.](image)

3.2. Research results
As part of the work, a set of works was carried out to determine the stress state in the rock mass of the +540 m horizon. The measurements were carried out in the workings of blocks No. 10, No. 20, No. 11, MBTs 10-20. In this section, a rock pressure station was laid in the form of 6 unloading slots according to the above method. The main parameters of the discharge slots are shown in Table 1.

| № slits | Slit length L | Slit depth | Slit height |
|---------|---------------|------------|-------------|
| 1в      | 330           | 120        | 1.3         |
| 2в      | 330           | 110        | 1.3         |
| 3г      | 340           | 110        | 1.15        |
| 4в      | 330           | 110        | 1.1         |
| 5г      | 330           | 115        | 1.2         |
| 6в      | 330           | 115        | 1.2         |

Table 1. Dischargeslots parameters.

The layout of the slots is shown in Figure 4. The depth of mining at the measurement site was 230 m. The average height of the slots above the working soil is 1.21 m.
Figure 4. The layout of the unloading slots on the mountains. +540 m Block 20.11.10. Intersection of haulage port No. 2 and haulage drift.

In the applied version of slotted unloading, the modulus of elasticity of rocks in the investigated area according to the data of static tests is $E = 9.03$ GPa, Poisson's ratio $\mu = 0.28$, the average radius of the slot is $R = 17.5$ cm; the average distance between the centers of the holes for the installation of benchmarks $l = 7$ cm; stress concentration factors $k_{\perp} = 0.03$; $k_{\parallel} = 0.07$.

Table 2. Stresses on the contour of workings.

| № of slot | № of point | design | Vertical stresses, $\sigma_v$, MPa | Longitudinal stresses $\sigma_{\text{л}}$, MPa | Transverse stresses $\sigma_{\text{н}}$, MPa |
|-----------|-----------|--------|-----------------------------------|-----------------------------------|-----------------------------------|
| 1в        | 1         |        | -65.7                             | -62.6 ± 1.10                       |
| 2в        | 2         |        |                                   |                                   |
| 3г        | 3         |        | -36.7                             | -64.2                             |
| 4в        | 4         |        |                                   |                                   |
| 5г        | 5         |        | -38.4                             | -63.3 ± 0.8                       |
| 6в        | 6         |        |                                   |                                   |

Analysis of the results showed that the stresses acting across the strike of the ore body are minus $-62.6 \pm 1.10$ MPa, along the strike minus $-63.3 \pm 0.8$ MPa. Vertical stresses are on average minus $-37.5 \pm 1.5$ MPa.
Due to the fact that external signs of rock funnel formation on the day surface have been identified at the deposits, but at the moment the deposit is classified as non-inclined to rock bursts, continuous monitoring should be carried out at the deposit, which must be carried out by specialized organizations and the mine surveying and geological service of the enterprise. Monitoring of the geomechanical state of the rock mass in order to timely detect possible zones of dynamic manifestations of rock pressure that may be associated with the redistribution of stresses during funnel formation.

3.3. Research results
The results obtained in the published works [10-16] suggest the directions of research and they must be carried out on a large scale, since the change in the size of the Earth and the accompanying change in the stress-strain state of the rock mass (Earth's crust) by the man-made disasters.

The collapse of the mined-out space of block No. 21 is a consequence of the process of displacement of rocks, which is provided for by the development system in accordance with the development project for block No. 21 sh. Siderite. As the general release progresses, the enclosing rocks fall on the broken-off ore and fill the worked-out space, forming deformations on the earth's surface. Deformation of the earth's surface unloaded the massif and structural elements of the development system, further manifestation of deformations of the day surface is possible as mining develops in the mine.

Based on the geological exploration, engineering-geological and hydro-geological work performed at the stage of exploration and additional exploration of the Novo-Bakalskoye and Shikhanskoye deposits, it was established that the hydrogeological and engineering-geological conditions of their development are simple. The ores and host rocks that make up the deposits mined by the Sideritovaya mine are not prone to brittle fracture under load. The main rock mass is represented by massive, unaffected by weathering rocks and ores. At the present time, according to the project, after the extraction of the main reserves of the block, the support pillars are extinguished, reducing the concentration of technogenic stresses. Taking this fact into account, it can be concluded that the main structural elements of the storey-chamber and sublevel-chamber development systems will be in a stable state after the pillars are repaid.

4. Conclusions
It has been established that at present no active tectonic disturbances, prone to movements in the form of mountain-tectonic blows, are observed at the Novo-Bakalskoe and Shikhanskoe deposits.

When assessing the potential rock burst hazard using the basic method - by disking of the core, areas of intensive disk disking along the core of exploration wells were not identified. On average, the core yield is in the range of 7-20 cm.

For the conditions of the area of occurrence of the Novo-Bakalskoye and Shikhanskoye fields, the first category of potential rock burst hazard has been established in terms of geodynamic zoning based on geomorphological and geophysical assessments of the field area.

An observation station for rock pressure was laid in block 20, block 10, in MBTs 10-20 of the field at a depth of 230 m (mountains + 540 m). In-situ measurements of natural stresses were carried out. The following values of natural stresses have been established: horizontal ones acting across the strike of the ore body are equal to minus -62.6 ± 1.0 MPa, along the strike minus -63.3 ± 0.8 MPa. Vertical stresses are on average minus -37.5 ± 1.5 MPa. The high stress values are explained by the fact that the mine workings where the measurements were made are in the rutting zone, access to the workings located in block 20, block 10, in MBTs 10-20 (mountains + 540m) must be limited.

Taking into account the established category of the area, in order to ensure the safety of mining operations, with a decrease in the depth of their conduct, it is recommended to periodically monitor the geomechanical state of the massif using basic methods - core displacement, visual observations, and instrumental surveying measurements. The main results of the work reflect the level of geomechanical knowledge about the mine today. As necessary, with the progress of mining operations, changes in mining and geological and mining technical conditions, the results can be adjusted after specifying a number of geomechanical factors.
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Acknowledgments
The studies have been performed within the limits of the state order No. 075-00581-19-00 (Theme No. 0405-2019- 0007).