Evaluation of geomechanical conditions at Magnezitovaya mine when undermining natural and anthropogenic objects

Roman Krinitsyn[1*], *Arkady* Avdeev[1] and *Sergei* Khudyakov[1]

[1]Institute of Mining of the Ural Division of Russian Academy of Sciences. Yekaterinburg, Russia.

Abstract: Development of Satka magnesite deposit is carried out in complicated geomechanical conditions, in particular, mining works are conducted under the Bolshaya Satka river, in the zone of influence of the existing and developed quarries. Underground workings undermine a number of surface objects of industrial and civil purpose: railways, bridges, buildings and structures. There was an urgent need to conduct special studies of geomechanical conditions at the mine in order to assess the feasibility of working off part of the safety pillars located under the railway tracks of "Russian Railways", PJSC and the river bed. In the process of research, the main physical and mechanical properties of rocks have been identified, and the initial natural stresses of the rock mass have been measured. An increased level of horizontal initial stresses in the zone of safety pillars at the horizons + 180. + 260 m was detected. Based on the results of the research, a conclusion was made on the need to develop some engineering measures to ensure the safety of underground works. It was recommended, to ensure the stability of the rocks massif, to apply the option of extracting the treatment chambers with the formation of the ceiling of the vaulted form. It is proposed to monitor deformation processes in mine workings and on the daylight surface. To this end, the installation of an automated control system for rock pressure is recommended. It is necessary to provide for the establishment of long-term observation stations for controlling rock pressure and displacement. According to the results of the research, "Guidelines for the safe control of mining operations at bump-hazardous Satka magnesite deposit" have been developed in accordance with the requirements of the Federal norms and regulations in industrial safety. **Key words:** physical and mechanical properties of rocks, initial stresses of rock massifs, full-scale measurements, laboratory tests, slit discharge, safety pillars, undermining of industrial and civil objects.

1 Introduction

Satka deposit of magnesites (the Southern Urals) is represented by a series of ore bodies of stratum and lenticular form, along a strike length of 1.3-3.6 km, along a dip of 100-500 m. The azimuth of the strike of ore bodies is $45 \div 55^0$, the angles of incidence southeastwards

[*] Corresponding author: roman_krinicyn@mail.ru

vary within $10 \div 850^0$ averaging $30 \div 45^0$, the normal thickness of ore bodies being in the range of $8 \div 30$ m.

The lithological section of the deposit is represented by a complex of stable sedimentary and metamorphosed rocks: magnesites, dolomites and shales of coaly-carbonaceous composition. Rocks of the diabase type, confined to the dyke veins of a steep fall with a thickness of up to 20 cm, have a minor distribution. Magnesite deposits are sometimes complicated by karst cavities. Active faults of the northeastern strike (azimuth 60^0) are low-amplitude faults.

In general, the entire sedimentary stratum is disintegrated by single systems of cracks of two types. The first type includes multidirectional cracks with vertical or close to them incidence angles up to the first tens of meters, often without aggregate, sometimes uncovered. The second type includes interstitial cracks located in magnesites strictly parallel to their bedding and characterized by a considerable extent along the strike and dip of ore bodies. The angles of incidence of cracks in the second group vary from $15 \div 20^0$ to $45 \div 50^0$, clearly repeating all the bends of the ore bodies.

The main development system for the extraction of ore at the deposit is currently a chamber-pillar system with dry backfilling of the worked-out space. The length of the mining block along the strike of the ore body at horizons +340 m, +260 m, +180 m with the chamber-pillar development system, taking into account the inter-block pillars is 240 m. The parameters of the chambers and pillars during the work-out of the treatment blocks, according to the recommendations of Institute of Mining of the Ural Division of Russian Academy of Sciences (IM UD RAS), have undergone several changes. For example, the width of the cleaning chambers increased from 8 m to 12-13 m, which led to an increase in the completeness of the excavation of magnesite and, consequently, to a decrease in losses and dilution of ore.

Since 2016, preparatory work is underway for the mining of the mine field by a sub-floor-chamber system with hardening backfilling of the worked-out space. The magnesite will be produced at horizon +100, and at horizon +180 the extension of the block No. 3 will be finalized with simultaneous preparation of the blocks No. 4, 5, 6 [1].

In the process of penetrating the buggy gangway and associated mine workings at horizon +180 m, some manifestations of rock pressure in the form of peeling and shooting with sharp sound and flying up to 3 m of slab-shaped pieces of rock with a transverse dimension of 100-300 mm and a thickness of 10-20 mm were noted. Given the tendency of the deposit's rocks to brittle fracture, the strength and elastic properties, the presence of high stresses in the rock massif, and on the basis of the calculated forecast of a bump hazard by the rock pressure laboratory, Satka deposit was classified as bump-hazardous, beginning from horizon +180 m (depth from the surface 250 m) and below. To monitor the stability of rocks IM UD RAS installed observation stations at the mine, consisting of deep frames, profile lines, photoelastic sensors. To automatically control the deformations of the rock massif, "Massiv 2" station was used. Continuous authors' supervision of the parameters of chambers and pillars during the cleaning of the treatment block was exercised, as a result of which the blocks ODB No.1, No.2 and No.3 were worked out without emergency situations [2, 4].

A significant part of the reserves of minefield I of Magnezitovaya mine is located under a number of protected surface infrastructure: tracks of "Russian Railways", PJSC and departmental tracks, the Bolshaya Satka river, railway and automobile bridges, industrial buildings and facilities, as well as private single-floor residential buildings. At present, the management of the mine plans to develop parts of the safety pillars located under the Bolshaya Satka river and the tracks of "Russian Railways", PJSC. In these areas, in addition to potential bump hazard, there is a risk of negative development of deformation processes, which can affect the stability of the daylight surface (Fig. 1).

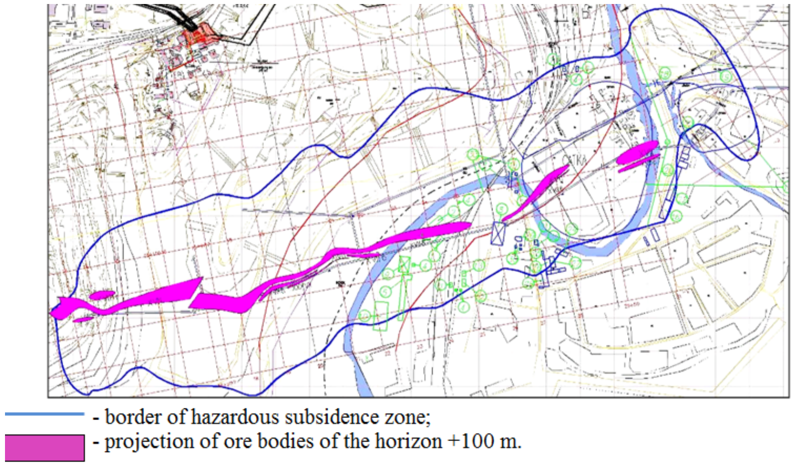

Fig. 1. Plan of the industrial site of Satka deposit

Therefore, there appeared an urgent need to conduct special studies of the geomechanical conditions of mine field I of Magnezitovaya mine in order to assess the possibility of a partial development of safety pilars located under the railways of "Russian Railways", PJSC and the river bed.

2 Methodology

In the course of the research work, instrumental measurements were carried out by the method of slot discharge, according to the methodology of the IM UD RAS, of the initial stresses of the rock massif near the location of blocks No. 4 and 5 at horizons +260 m and +180 m.

In places of full-scale measurements of the rock mass, samples of the main lithological varieties were taken, prepared and tested for strength properties. A total of six samples of the main lithological varieties from the operational blocks No. 4, and 6 were selected; samples being core and lump. In the course of the research, thin sections were made, through which petrographic diagnostics of the tested rocks was carried out in order to identify the possible dependence of the physical and mechanical properties of rocks on their petrographic composition, structure and texture.

In order to develop some engineering measures to ensure the safety of underground operations, mathematical modeling of anthropogenic stresses in the roof of chambers of various configurations by the method of finite elements was made.

3 Results

According to a petrographic analysis of rock samples, it was established that the samples under study are calcareous dolomite, magnesite, diorite. The main minerals are dolomite, magnesite, amphibole, calcite, plagioclase, epidote, pyroxene, quartz. Hydrothermal mineralization is represented by two samples: dolomite with hydrodermal vein and hydrothermally altered diorite. Hydrothermal mineralization strengthens the original rocks. Four samples are not affected by hydrothermal processes, the crystal sizes in these samples reach 2-6 mm, which significantly reduces the strength properties of the rocks. Lenticular, nonuniform and layered textures of the majority of the presented samples characterize the anisotropy of strength properties of rocks.

According to the results of finding of the strength properties of rocks, it has been established that in the naturally dry state the tensile strength at compression of the dolomite is 120 MPa, in the water-saturated state - 118 MPa (Table 1). For limestone, these figures are 131 and 96 MPa, respectively, for magnesite - 56 and 47 MPa; for diorite - 137 and 126 MPa. The tensile strength of rocks varies from 5 to 35 MPa for dry rocks and 4-29 MPa for water-saturated rocks. It is generally seen that rocks with water saturation reduce the strength properties slightly, i.e. are waterproof. The rock strength varies widely from 4 to 14, averaging 7-8. The average clutch of rocks is 19 MPa, the angle of internal friction is 27-34 degrees.

It should be noted that earlier, when developing a project for the use of a deposit (in the 1990s), according to the data of detailed exploration, significantly higher strength parameters of rocks were established: for example, for dolomite 190 MPa for compression, for magnesite 110 MPa. Thus, the strength of magnesite in the investigated sites is half that of dolomite adopted for the project (1.6 times).

Taking into account the coefficient of structural weakening of rocks in the massif (0.4-0.5), the strength of the massif on the sections under study for compression will be 17 ... 55 MPa, averaging 39 MPa; for a tension of 1.5..14 MPa, averaging 5 MPa.

Table 1. Physical and mechanical properties of rocks

Rock name	Air-dried basis					Water-saturated basis				
	σ_{comp}	σ_p	f	φ	C	σ_{comp}	σ_p	f	φ	C
Samples made from core material										
Mica limestone	131.0	6.7	7	-	18	96.4	6.4	6	-	16
Dolomite	106.6	5.6	6	-	17	120.8	5.8	7	-	16
Magnesite	44.4	4.8	4	36	8	42.4	3.7	4	38	8
Samples made from lumps										
Magnesite	67.7	10.5	6	37	13	41.1	6.5	6	22	12
Dolomite	132.2	20.3	10	35	24	115.9	16.4	10	30	25
Diorite	137.3	35.4	14	26	34	126.2	29.4	13	20	38
Note: σ_{comp} - compressive strength, MPa; σ_p - ultimate tensile strength, MPa; f - rock strength according to M.M. Protodiakonov; C - cohesion, MPa; φ - angle of internal friction, deg.										

To estimate the initial stressed state of the rock massif on the investigated areas, processed under the Bolshaya Satka river and railway tracks connecting Bacal city and Berdyaus junction station, in-situ measurements were carried out by the method of slit discharge [3].

Measurements were made at horizons +260 and +180 m in the area of blocks No. 4 and 5. As a result of measurements at horizon + 260 m, the stresses in the massif were: vertical - minus 14.2 MPa, horizontal along the strike of the ore body - minus 23.3 MPa, horizontal crosswise the strike of the ore body is minus 24.5 MPa (the minus sign means compression of rocks). Stresses are gravitational-tectonic. The ratio of the lateral extension is 1.64-1.73.

At horizon +180 m the initial stresses reach the values: vertical - minus 29.8 MPa, along the strike - minus 48.6 MPa crosswise the strike - minus 51.6 MPa.

Such a sharp increase in voltages in 1.3 – 2.1 times on almost adjacent floors can be explained by the fact that the sites of the installation of rock pressure observation stations pass near the spent and filled up Gologorsky quarry, and the workings of horizon +180 m, moreover, are located almost under the bottom this quarry, i.e. are under the influence of increased concentrations of stresses of anthropogenic nature.

It should be noted that in 2006 [2] the specialists of IM UD RAS found that the dry filling applied at Magnezitovaya mine practically does not affect the bearing capacity of the pillars, i.e. lateral pushback is small. The same can be said about the effect of filling the quarry on its contouring workings. Thus, backfilling of a quarry with empty rocks does not reduce the concentration of man-made stresses on the contour. Workings, passable directly near the bottom of the spent quarry, will thus be subject to increased rock pressure and be unstable, especially given the permissible stresses in the massif (55 MPa).

Therefore, when working off the areas located near the contour of the spent quarry, it is necessary to pay close attention to the compliance with the design constructive parameters of the cleaning blocks, to constantly monitor the stress-strain state and deformation processes, and to develop additional measures to ensure the safety of mining operations.

In order to develop technical measures to ensure the safety of underground work, mathematical modeling of anthropogenic stresses in the structural elements of the systems using the finite element method was additionally carried out.

Modeling the roof of the cleaning chambers of various shapes for the variants of the working parameters showed that when forming the overhead roof of the chambers, the rock mass at the base of the vent ort will be destroyed (Fig. 2a). In the rock massif located at the base of the vent ort left and right there will be tensile stresses reaching the value plus 1. .. plus 2 MPa, this will lead to a partial collapse. The use of a polymeric anchor support for fixing these places will be of little effect since these bars work well for stretching, and for cutting they are less effective.

The vaulted roof of the chamber (Fig. 2b) will be more stable. When modeling the vaulted form of roof of the chamber, it was established that the vaulted shape of the ceiling will allow more even distribution of the load and reduce the likelihood of the manifestation of rock pressure.

Thus, with a camera height of 14 m, man-made stresses on the contour of the vaulted chamber are of a compressive nature. In the working walls, the horizontal principal normal stresses reach a level of 0 MPa. The vertical principal normal stresses in the walls are minus 16 ... minus 2 MPa. The level of stresses obtained does not exceed the compressive strength of the massif. The massif will be in a more stable state, in comparison with the overhead form.

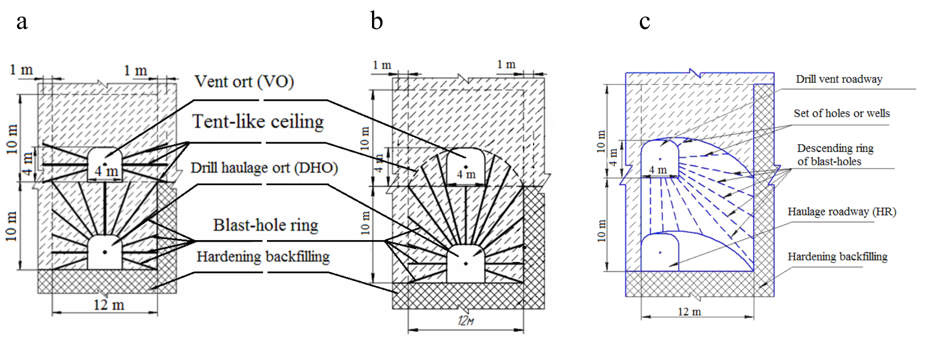

Fig. 2. Options for the chamber with the formation of a) the overhead form of roof of the chambers, b) the symmetrical vaulted ceiling of c) the asymmetrical vaulted ceiling

Based on the results of the modeling, the engineering services of Magnezitovaya mine are recommended for a sub-stage-chamber development system with hardening backfilling of the worked-out space, to ensure the stability of the rock massif, the option of forming chambers with the formation of ceiling of a vaulted shape should be applied.

It should be noted, however, that in the roof of the chamber there is an increased level of stresses, reaching a level of minus 58 .. minus 92 MPa from the action of horizontal forces, minus 5 .. minus 23 MPa from the action of vertical forces. In weak rocks, man-made stresses will exceed the allowable compressive stresses.

Therefore, in low-strength and unstable rocks, it is proposed to give the roof an asymmetrical vaulted shape as an additional measure (Fig. 2c). Thus, modeling the stress of the near-edge massif of chambers of an asymmetric vaulted shape at a chamber height of 14 m showed that when the chamber of the first stage (the under-roof layer) is formed, the horizontal stresses in the roof reach minus 36 .. minus 39 MPa, in the soil - minus 21 .. minus 24 MPa, in the wall - minus 3. minus 9 MPa, the concentration of stresses in the lower corner of the vaulted wall (-51 MPa) is observed. Vertical stresses in the roof are equal to 0 .. minus 3 MPa, in the soil - 0 .. minus 1 MPa, in the wall - minus 30 .. minus 40 MPa, in the lower corner of the vaulted wall there is also an increased concentration of stresses (-78 MPa). Since the stress concentrators in this variant are directed to the soil of workings, the contour massif in the roof and walls of the chamber will be in a more stable state.

4 Conclusions

Based on the above, the authors draw the following conclusions

1. The rocks in the undermined safety pillars of railway tracks and river bed are mainly represented by calcareous dolomite, magnesite, diorite. These rocks are prone to brittle fracture, being anisotropic and waterproof. Strength properties in the investigated areas are much lower than those adopted in the design solutions. The compression strength of the rock massif is on the average 39 MPa; the tensile strength is 5 MPa.

2. An increased level of horizontal initial stresses has been found in the zone of undermining safety pillars at horizons +180 .. +260 m. The coefficient of lateral expansion (ratio of horizontal stresses to vertical ones) is 1.63-1.73. The horizontal stresses acting in this part of Satka deposit are 80-85% or more of the ultimate strength of the rocks of the massif composing the area under investigation.

3. It was found that the level of initial stresses, in addition to natural geological factors, is significantly influenced by closely located old quarries. When testing the sections located near the contour of the spent quarry, it is necessary to monitor the changes in the rock pressure, deformation processes, displacement, and develop additional measures to ensure the safety of mining operations.

4. As technical measures to ensure the safety of underground work, it is proposed to design the ceiling of the cleaning chambers in the form of a symmetrical and asymmetric vault. It is established that in this case the stress concentrators are led to the soil of the excavations, the level of destroying tensile stresses decreases, the contour massif in the roof and the walls of the chambers is in a stable state.

5. Control over the change in the deformations of the massif in the mine workings while undermining the safety pillars is proposed to be carried out with photoelastic sensors, which allows for continuous fixing the change in the stressed state of the massif.

6. It is recommended to install the system "Gradient" ("NTTs Automatika", LLC) for automated control of rock pressure (ASCRP).

7. In addition, provision should be made for the installation of long-term observation stations for controlling rock pressure, shifting in the form of deep benchmarks, profile lines, photoelastic sensors in underground workings and profile lines and benchmarks on the daylight surface.

8. Based on the results of the research, "Guidelines for the safe management of mining operations at Satka magnesite deposit prone to bump hazards" have been developed in accordance with the requirements of the Federal norms and regulations in the field of industrial safety. The Guidelines set out the rules for the safe conduct of mining operations in areas prone to and dangerous for bump hazards, methods for assessing the bump hazard, measures for preventing dynamic manifestations of rock pressure, and methods for calculating the walling and supports of mine workings.

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