Estimation of impact of rock conditions on the conveyor workings geometry by means of geophysical methods

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Abstract. This paper presents the results of a comprehensive survey of a coal-bearing rock mass conducted by means of a combination of geophysical methods. The task of a comprehensive survey is to establish the relationships between the manifestations of mining and geological processes in the preparatory workings and the parameters of electromagnetic emission and high-frequency radio wave scanning. The estimation of the parameters of unsteady geophysical fields, resulting in the stress-strain state of the rock mass, was carried out using the ANGEL-M complex. The assessment of decompression and the presence of fracturing of rocks around the belt road was performed by the OKO-2 GPR system. Analysis of the results of the examination of underground mine workings using the "ANGEL-M" and "OKO-2" complexes shows a high degree of convergence of the state of the workings and instrument readings. Cave-in places of in the workings are located in high amplitude regions of radio waves. Identification of the development sites prone to geodynamic manifestations will allow to take measures for strengthening the frame support in advance, preventing deformation of the extensible belt conveyor. The implementation of a comprehensive survey will improve the reliability of transport conveyor lines and the safety of mining operations.

1. Introduction

The first experience in predicting the rock-bump hazard at mines that develop layers prone to rock burst shock has shown that conventional (direct) methods for determining the stress state of rock mass (the dust coal output method) are very time-consuming and non-operational. As a rule, their information content and reliability are limited to individual local sites, and require a large amount of drilling of trial boreholes for a comprehensive assessment of the rock-bump state over vast areas (for example, a breakage face).

In order to overcome such difficulties, the country's leading institutions (All-Russian Research Institute of Mining Geomechanics and Survey, the "VostNII" Research Center on Industrial and Environmental Safety in the Mining Industry, Kuzbass State Technical University) have developed geophysical methods for assessing the stress state of the rock mass and predicting the rock-bump hazard of coal seams and ore deposits based on the generalization and analysis of long-term observations made at coal mines in Russia. The majority of these methods have been tested for many years and have taken a worthy place in the list of the most promising geophysical methods for predicting rock-bump hazard at mining enterprises of Russia.
One of the main advantages of geophysical methods is the ability to estimate the average stress in a sufficient volume, often without drilling trial boreholes in the rock mass, which greatly facilitates and accelerates the process of evaluating its stress state and rock-bump hazard.

2. Problem Statement
The demand for geophysical methods for monitoring the rock-bump hazard, especially at the present stage of ore and coal deposits development, is largely due to their (methods) technological capability. The qualitative changes that occurred in the element base and in computer technologies significantly contributed to the process of developing new effective technological schemes for implementing and using geophysical methods [1–7]. The list of geophysical equipment developed for the practical application of various geophysical methods for predicting the rock-bump hazard of coal seams has significantly changed and expanded.

This article contains the results of a comprehensive survey of the belt road with the use of geophysical methods on the example of the 3-2-7 "Sibirginskaya" mine.

Figure 1 presents a section of the 3-2-7 lava-mining plan, which shows a part of the belt road bearing the same name that is subject to complete cave-in in the specified places, having an intense manifestation of heaving.

The main task of a comprehensive survey is to identify the relationships between the current / past manifestations of mining and geological processes and the results of readings of such geophysical survey devices as ANGEL-M (determination of electromagnetic emission) and the OKO-2 GPR (based on high-frequency radio-wave scanning).

![Figure 1. The section of the lava-mining plan for the 3-2-7, belt road.](image)

The ANGEL-M device was used to measure the site of the 3-2-7 belt road at the range of 54–34 pickets.

3. Findings
A summary diagram of the ANGEL-M readings for the soil from the 3-2-7 belt road is shown in figure 2. Such a comprehensive presentation of the results makes it possible to evaluate changes in the readings of the device, both depending on the position of the device and measurements along the workings and depending on the depth. The preliminary assessment of the situation clearly indicates an increased level of readings in the contour rock mass. The influence of anthropogenic noise is highly likely.
**Figure 2.** A summary diagram of the ANGEL-M device readings when examining the soil of the 3-2-7 belt road.

Figure 3 clearly shows the dependence of the level of the received signal not only on the depth, but also on the site in the workings being examined. When moving away from the lava breakage face, the signal level decreases.

**Figure 3.** Picket distribution of the ANGEL-M readings with AES function depending on the depth.

Figures 4 and 5 show the total and average signal intensity received by the ANGEL-M device with the AES function.
Figure 4. The total signal intensity received by the ANGEL-M device with the AES function.

Figure 5. The average signal intensity received by the ANGEL-M device with the AES function.

The graphs constructed on the base of approximating the results also indicate an increased level of readings at a distance of up to 100 meters near the front of working face.

In this case, the maximum value of the amplitude of a high-frequency radio wave passing through a rock mass is taken as the amplitude.

The diagram on figure 6 also presents the obvious dependence of the reading values on the position relative to the developed site. At all the surveyed depths, the amplitude of the passing wave decreases with the distance from the breakage face.

Presumably, the amplitude with proper calibration for specific mining and geological conditions, it is possible to assess the stress state (tendency to cave in) of the rock mass, and consequently to timely take the necessary measures to ensure the proper level of safety.

Figure 7 and figure 8 show the values of the total and average signal amplitudes.

When comparing the results of the two devices used – ANGEL-M with the AES function and OKO-2, it is possible to conclude with a high degree of probability that the results correlate with each other.
Figure 6. The diagram presenting the results of georadiolocation studies of the soil from the 3-2-7 belt road.

Figure 7. The values of the total signal amplitude of the georadiolocation survey of the soil from the 3-2-7 belt road.
Figure 8. The values of the average signal amplitude of the georadiolocation survey of the soil from the 3-2-7 belt road.

The comparison of the state of workings presented in the plan on figure 1 and the diagrams on figure 7 and figure 8 diagrams is of particular interest. The high convergence of the cave-in sites indicated on the plan and the excess of the amplitudes of passing radio waves relative to the average (approximated) level can be clearly seen on them.

4. Conclusion

As a result of conducting a comprehensive survey using several geophysical methods, the following dependencies were identified:

– the results of surveys of workings using the ANGEL-M with the AES function and the OKO-2 devices indicate the presence of dependencies between the rock conditions and the data obtained;
– the front of the working face of the 3-2-7 belt road of the "Sibirginskaya" mine is detected at a distance of up to 100 m;
– the high degree of convergence of the state of workings and the readings obtained indicate the possibility of identifying high-stress and prone to cave-in zones of the rock mass;
– the excess of the amplitude of the radio wave passage in georadiolocation studies above the average value with a high degree of convergence coincides with the sites critical for the possibility of cave-in.

Based on the comparison of the geophysical survey data obtained from the wind roadway and belt road, the increased stress in the rock mass is observed at the distance of 80–120 m from the front of the working face. In places where less stress was recorded, unloading has already occurred in the form of falls and cave-in.

In this regard, it is relevant and timely to apply such a comprehensive approach for systematic monitoring of workings, identifying critical values for stresses simultaneously with readings obtained using these methods.

If there are known (identified by a series of measurements) threshold values of geophysical methods and planned measurements of indications, it is possible to determine critical areas of workings that are prone to cave in.
The analysis of soil heaving and lining deformation. As a result of the simulation analysis, it was revealed:

– internal stresses in the enclosing carbon-hydrogen mass in comparison with 35 and 55 pickets along the belt road present a similar situation. This indicates that the emerging phenomena associated with the collapse and fall of the roof, have little correlation with the progress of the working face front;

– the coefficient of residual strength is distributed in the section along the belt road in such a way that it directly indicates the possibility of deformations of workings, similar to those that have already occurred.

Figure 9, 10 shows sketches of the belt road geometry after the dynamic phenomena that occurred in March 2018.

![Figure 9](image-url)

**Figure 9.** The geometry plan of the belt road with the designation of the axes of the reinforcing frame support (05.07.2018).

![Figure 10](image-url)

**Figure 10.** The geometry of the belt road in cross-section along the axes of the reinforcing frame support (05.07.2018).

The stress distribution pattern (figure 11) shows that the presence of workings and the first lava layer of 3-1-7 changes the uniformity of the resulting stresses from horizontal to vertical layers, which is due to the presence of anthropogenic voids that contribute to the discharge directions.
When comparing figure 10, 11, a complete convergence of the dynamic phenomena that occurred and the results of simulation using finite element analysis is revealed.

![Figure 11](image-url)

**Figure 11.** The pattern of relative distributions of internal stress values in the rock mass.

The results of simulation calculations indicate a critical level of internal stresses in the rock mass, which fully decompresses a significant part of the coal-bearing rock mass containing the considered workings. With such patterns of critical internal stress distributions, any dynamic phenomena can contribute to the development of destructive or critical loads for the support. Thus, it can be concluded that at a certain stage of operation of the workings under consideration, there were external factors that critically affected the increase in internal stresses in the hydrocarbon mass.

As a result of geomechanical processes that contribute to the movement of rock masses, the main vectors of free movement are the roof on the side opposite to the extraction pillar, as well as the soil – which was observed in regard to the fact of heaving.

Changes in external factors (an increase of cave-in in rock mass on the surface of the ground, the probability of the rock burst shock), which significantly increase the stresses affecting the hydrocarbon mass, could not be taken into account when making recommendations for fastening, which led to a critical discrepancy between the loads and the load-bearing capacity of the frame support.

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