Justification of method of continuous measurements of position of sides of surface mine

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Abstract. As a result of full-scale surveys of parameters of open mining facilities, a set of discrete values is basically obtained. The geomechanical state of the ledges of the sides of the pit and dumps can not be fully represented without obtaining objective information about the dynamics of the deformation regime of the observed object. This information is necessary throughout the life of the quarry, in order to ensure its trouble-free operation. Thus, effective monitoring of the ledges of the sides of quarries and dumps is a necessary part of the mining safety system for the enterprise, and also allows checking the correctness of the previously adopted design solutions for setting the sides and ledges of the quarry to a stationary position. This paper presents a measurement technique that allows obtaining continuous data in real time to ensure the safety of work.

1. Introduction. The purpose of observations is to obtain information about the presence or absence of a process of displacement at the time of observation. Timely detection of the onset of the shift process is necessary for the rapid assessment of the degree of danger of these deformations and the adoption of measures that outstrip their development, contributing to the safe conduct of mining operations, and also excluding the stopping or reduction of production volumes. In many cases, the most dangerous are sudden landslides, the manifestations of which are extremely difficult to predict. Before the appearance of landslides and caving, there is an increase in the rate of subsidence, which can only be tracked in real time [1]. To date, the most effective method of observing shifts in open mining is the observation station, which is a network of observational benchmarks, developed on the basis of the general to the particular principle with a three-level structure: the reference benchmarks are located behind the shift zone and are conditionally immovable and serve to link long-term observation stations, the long-term benchmarks serve to control the generation of deep destructive deformations and determine the coordinates of temporary benchmarks [2].

Long-term observational benchmarks (LOB) are laid on potentially stable areas, excluding small-scale deformations.

Temporary observing benchmarks (TOB) are laid to control near-surface deformations of individual sections; sites with a low stock factor; for the study of sites, with a complex poorly studied bedding of rocks; for the control of particularly critical areas, for example, in the places of excavation of legal stocks; to assess the effectiveness of anti-landslide measures [3]. The term of existence of temporary stations does not exceed 1 to 5 years. The measurement process at the described observing stations is a cyclic repetition of a set of mine surveying operations to obtain the coordinates of TOB’s relative to LOB’s. This stage reflects the main problem of the measurement method under consideration: due to the complexity of the measurement operations with the aid of an observation station, it is not possible to obtain continuous values in real time [4]. To prevent sudden landslides, a fundamentally different measuring technique is required, the result of which is a continuous value.

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2. Research methods. As a research object, the mines of the Blagodatnoye deposit, the Gold Mining Company Polyus, 1087 and 1816 m long, 290 and 430 m in depth, were taken, respectively. The above-described observation station system with TOB and LOB is used in these quarries [5]. The methodology for performing instrumental observations includes two main stages:

1. Monitoring of long-term observation benchmarks using satellite receivers.
2. Tracking the temporary benchmarks using a total station.

Satellite measurements are performed using three or more satellite receivers in the static mode, working simultaneously with the subsequent estimation of residuals in closed figures and equalization of the network. Thus, a network diagram of observations is realized (Figure 1), which ensures high accuracy within the limits of permissible errors in measurements.

![Satellite measurements scheme](image)

*Figure 1. Satellite measurements scheme*

In view of the fact that temporary working benchmarks are located in a potentially dangerous zone, periodic installation of an expensive receiver in these benchmarks is impossible. Tracking of working benchmarks is performed by means of an electronic total station, sighting objects are relatively inexpensive reflectors fixed by the surveyor before the shifting process begins. The coordinates of the reflectors should be determined with an accuracy that allows determining the displacement and deformation of the object. The periodicity of measurements at this facility was determined depending on the fixed displacement rate (Table 1).

| Displacement speed, mm/day | Periodicity of measurements, days |
|---------------------------|----------------------------------|
| 0.5                       | 150                              |
| 1.0                       | 75                               |
| 2.0                       | 40                               |
| 5.0                       | 15                               |
| 10.0                      | 8                                |
| 20.0                      | 4                                |

As can be seen from Table 1, even with the maximum shifting speed, the measurement periodicity is 1 time per 4 days. The experience of quarrying shows that the caving process can be activated within a few hours. The probable collapse of the quarry side is predicted from data on the increase in the shifting speed. The necessary data can be obtained from measurement data at observational stations (Figure 2).
The rate of subsidence during such measurements is usually detected after a certain time after the processing of the last cycle of observations (September of 2016 in Figure) and, possibly, will provide the necessary information after the collapse [6]. It is obvious that the maximum frequency of measurements will not allow one to identify a dangerous increase in the speed of the displacement in time. Increased measurement productivity can be achieved through the use of robotic monitoring stations. The robotic total station is able to continuously monitor; however, under conditions of the open-pit operations constant use of this equipment will lead to depreciation and the corresponding costs. In addition, even with constant monitoring, the information received will still not be discrete.

The solution to this problem can be the application of the MSR-300 radar scanning system, which provides a continuous mode of operation [7]. The field unit of the system is a combined circuit (trailer), which includes a short-wave radar with a shooting range of 2500 m, an on-board computer, a computer unit and a weather station. (Figure 3.)

A satellite receiver or a reflector for working with electronic total stations is provided to coordinate the position of the system. The algorithm of the system allows continuous monitoring of the pit edge in real time and with a wide coverage, the computing blocks of the system after processing generate a
three-dimensional model of the object with the possibility of continuous tracking of displacements. Data from the radar are transmitted to computers in the central office by radio or mobile communication, where they are processed and graphically displayed for direct visual control. Data can also be monitored directly from the radar installation. When the displacement speed reaches the set critical value, the system notifies with an audible signal, color scale, information on the monitors of the computers of the geotechnical monitoring service and responsible persons of the quarry. If necessary, it is possible to integrate the radar system into the quarry regular alert system, which will allow timely protection of workers and equipment and, possibly, apply any measures to prevent collapse. One complete scan cycle (full quarry edge position measurement, model construction, sending the information) of the main region, defined for the South quarry of "Blagodatnoye" deposit, is about 4 minutes in time. The dispatch of the analytical note, with attachments (a screenshot of the scanned regions, displacement velocity graphs) is performed twice a day. The shortcomings of the system include relatively low accuracy of coordination in the world coordinate system, which does not allow a single radar system to provide full control of the sides of the quarry. For this reason, a combined scheme of observations is used:

- the classical scheme of the observation station makes it possible to obtain of measurements high-precision graphs of the current state of the quarry sides as a result and to ensure a long-term tracking of the dynamics of deformation processes
- the radar system for ensuring the stability of the sides of quarries allows one to provide constant monitoring of the side and timely notification of potentially dangerous increases in displacement rates at a relatively low cost [7].

3. Research results.
The survey of the side of the southern quarry was carried out to test the feasibility of introducing a measurement technique using a radar scanner. The main measurement period was in August 2016 - April 2017 (Figure 2). The first series of observations showed the values of the displacement speed of the benchmarks at a level of about 1.0 mm / day. The value is permissible; however, the second series showed that the absolute speed of benchmark displacement is within 2.5mm / day. These speeds are also acceptable, but indicate a tendency to increase in speed. The accumulated displacements reach values of 215 mm. An abrupt increase in the rate of subsidence can lead to large cracks; it is possible to track these trends with point measurements only by increasing the frequency of surveys. This fact makes it advisable to use radar that provides continuous scanning of the bead.

4 Conclusions .
The geotechnical monitoring system is aimed, first of all, at the safety of mining operations. The radar system MRS-300 in real time can warn about the onset of instantaneous landslide processes, and allow people and equipment to be withdrawn before the collapse if it is impossible to take other measures. The observation station allows a long-term study of the stressed state of the open-pit rock mass, determining the stability factor, studying the pattern of development of deformations and, in the long term, creating local observation stations according to predefined profile lines for a detailed study of the quarry site [8]. Based on the results of observations, it is possible to identify the character and assess the degree of danger of deformation, and to give an appropriate forecast.

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