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APPLICATION OF THE GROUND LASER SCANNING RESULTS IN MONITORING OF ADJACENT ROCK MASSES OF DEEP CAREERS

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Abstract: *The method of laser scanning, used in combination with the traditional mine surveying, is one of the most effective and safest ways to carry out mine surveying and instrumental observations on deforming areas of open mining objects. The article presents the results of ground-based laser scanning of the Kharanutsky coal pit and a comparative analysis to determine the deformations and displacements of the sides for different periods, which was performed in the RISCAN PRO environment. Digital elevation models (DEM) were built, distinguishing observation cycles by color. As a result of comparison, the places of manifestation of deformations and displacements were revealed. Based on the results of geomonitoring, it was concluded that critical displacements and deformations were not detected, despite the places where small rockslides were manifested, and further systematic observations were recommended. The results of laser scanning are confirmed by the data of satellite observations on the control points and the survey of the section sides.*

Key words: *ground-based laser scanning, quarry, near-field array, geomonitoring, GPS, scan position, point cloud.*

Introduction. The current state of open pit mining, especially deep open-pit mines of Kharanutskiy LLC, which have reached a depth of more than 500 m, requires the organization of systematic instrumental measurements on the sides based on the laid down observation stations, in the form of metal benchmarks, taking into account the developed laying and observation schemes. This makes it possible to monitor and predict the state of the rock massifs in open pits.

In order to organize geomonitoring of mine surveying observations of the state of opencast slopes, it is necessary to do the following: select potentially unstable areas based on the analysis of engineering-geological and mining-technical conditions of development for laying observation stations; to develop a design for an observation station for deformations of the slopes of the sides of open pits and dumps; to carry out the laying of benchmarks of observation stations at the quarry; to perform binding of reference marks with determination of coordinates X, Y, Z to the nearest points of the reference geodetic network; select the positions of the control points of the profile lines; determine the position of the observation point of the measuring station of the system being created; to carry out systematic control over the invariability of the position of measuring stations using GPS receivers (satellite positioning system); instrumental measurements according to the benchmarks of the profile lines of the observation station; processing of the results of instrumental observations and their analysis [1,2].

The layout of the profile lines of the observation stations should be selected on the basis of an analysis of the state of the side masses and slopes of the dumps, the current state of mining and the prospects for their further development. To ensure a long service life, reference benchmarks, control points and points of measuring stations are proposed to be installed in the form of a permanent reinforced concrete pillar.

In the monitoring system being created, it is proposed to monitor the state of the pits and dumps by a semi-automatic method. The semi-automatic observation system is based on the production of systematic instrumental surveying and geodetic observations of the displacements and deformations of the working benchmarks of profile lines using an electronic total station and GPS receivers to control the invariability of the position of control points and measuring stations, and in the mathematical processing of observation results [3].

Objects and research methods. The area is rich in mineral deposits: Kharanutskoe coal deposit, Burpalinskoe copper deposit, Golevskoe synnyrites deposit, Katuginskoe cryolite-rare earth-rare metal deposit, Kitemyakhtinskaya gold placer, Olondinskoe lithium deposit, Udokan copper deposit-Chineyskoe and titanium iron deposits Chitkandinskoe coal deposit, Yuzhno-Sulumatskoe iron deposit, etc. (Fig. 1).

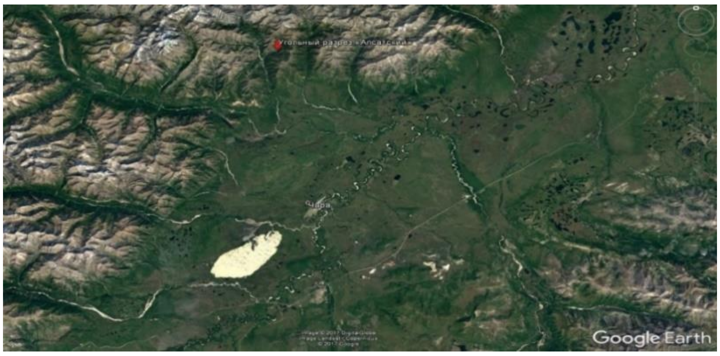


Fig. 1. Layout of the work site

According to the terms of reference for the performance of work, it was required to: draw up a work program; perform instrumental observations on the Kharanutsky section with a length of no more than 2500 m; to create observation stations for performing instrumental observations of the deformation of the cut sides; the work must be performed in accordance with the requirements of the current regulatory and technical documentation [4].

Topogeodetic work begins with the collection of auxiliary information (diagrams, drawings, map materials) from the responsible representatives of the Customer. On the basis of mine surveying and geodetic maps and plans, ideas were obtained about the nature of the relief, the location of the GGS points, relative to the work site. Further, the reconnaissance of the object was carried out.

At this stage, the following are carried out: visual assessment of the object; clarification of the boundaries of the object; the ability to conduct satellite and linear-angular observations.

Based on the results of the reconnaissance of the work area, conclusions were drawn about the methods of conducting instrumental observations. A work program has been drawn up [5].

In the "Static" mode, GNSS receivers installed at the initial and determined points simultaneously collect data from all satellites visible in the area. Data collection at points continues for a period of time, depending on the distance between the receivers, the state of the constellation of satellites, obstacles that affect data collection (trees, buildings, mountains, etc., blocking part of the sky).

Satellite measurements were performed in a static mode, in sessions (sessions) with the duration of synchronous observations by a pair of receivers at the points that form the spatial vector, not less than thirty minutes. At the same time, special attention was paid to the choice of the most favorable time intervals, when the simultaneous visibility of 10 satellites was ensured [6].

The static measurement method is the most accurate of any other GNSS survey method. This is mainly due to the increased collection time of measurements, and, consequently, with the large volume of measurements required for statics.

The survey of the side of the coal mine was performed using a ground-based laser scanning system RIEGL Z-400I [8].

Advantages of the method of ground-based laser scanning over tachymetric survey and other types of ground-based survey: portable, durable, economical; served by one person; instant three-dimensional visualization; high accuracy; incomparably more complete results; fast data collection; ensuring safety when shooting hard-to-reach and dangerous objects [7].

The material costs for collecting data and modeling an object using three-dimensional ground-based laser scanning methods are comparable to traditional survey methods in small areas and objects, and lower in areas of large area or length. Even with comparable survey costs, the completeness and accuracy of the results of terrestrial laser scanning make it possible to avoid additional costs during the design, construction and operation of the facility.

Scanning control and transformation of the scanner coordinate system are carried out by the RISCAN PRO and MicroStation software supplied with the scanner [9,10].

On the work area, a complex of field work on ground laser scanning was carried out, consisting of the following types of work:

1. Reconnaissance. Survey work using a ground-based laser scanning system begins with the collection of auxiliary information (diagrams, drawings, map materials) and a reconnaissance of the object is carried out.

2. Creation of a survey rationale required to determine the coordinates of reference marks (external orientation elements of the scanner). Reflective marks were temporarily fixed on the ground at special landmarks. For stability, the milestones were fixed with bipods.

3. Scanning was performed using a RIEGL Z-400i ground-based laser scanning system. Scanning parameters: L-950m, frequency range 150kHz: t-24 min, fixation of the last reflection with maximum angular sweeps (Fig. 2-4). To scan the side of the section, 4 points of the device were required. The placement of scan positions meets the following requirement: from the scanning point all mine workings and elements to be displayed are clearly visible. Scanning at each station was carried out in 2 stages: performing high density scanning; recognition of reflective marks [11].

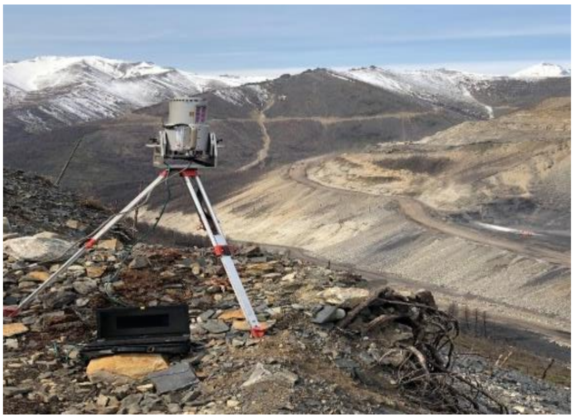


Fig. 2. Installation on the operating point of the RIEGL Z-400I scanner

To orient the point clouds (obtained during scanning at each scan position) between each other in one coordinate system, reflective marks are needed, which are fixed on the ground during scanning.

Results and its discussion. Coordination of marks was carried out from survey points using TRIMBLE R8-III GPS receivers.

Digital data processing includes the following steps:

1. Transformation (landing) of the cloud of points obtained by scanning using files of coordinates of points of reference justification in a certain coordinate system.
2. Creation of a digital terrain model. The primary processing of the scan results was performed using the RISCAN PRO and MicroStation software, further processing and construction of the topographic plan were performed using AutoCAD Civil 3D [12].

Completeness control is carried out by comparing the material ready for transfer with the terrain. In this case, both the facts of lack of information and the facts of redundancy of information are recorded.

The coverage of the object was controlled by the summary file of the discharged points of laser reflections from all scans.

Control is necessary at every stage of the work, since the modeling process is quite long and errors can be detected long time after the end of the survey. The accuracy of determining the reference marks is also controlled.

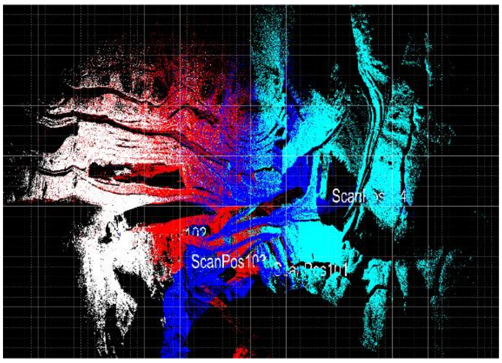


Fig. 3. Location of scan positions (October 2019)

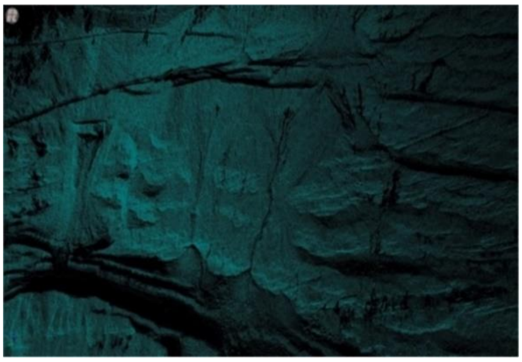


Fig. 4. Dense point cloud after scanning

Point cloud transformation is carried out in the RISCAN PRO program with a marginal error not exceeding 1-2 cm. In case of exceeding the permissible errors, the coordinates of the marks are redefined, or a rescanning is performed. The transformation of the point cloud into the coordinate system adopted at the work object is carried out using reflective marks. It is necessary that for each reflective mark the coordinates were determined: in the coordinate system adopted at the object of work; in the conventional coordinate system of the scanner [13,14,15].

A file with the coordinates of marks in the coordinate system adopted at the object of work (global coordinates file) is created based on the results of coordinating marks from the points of the survey justification.

The file of marks in the conventional coordinate system of the scanner is created as a result of the 2nd stage of scanning at the station (recognition of marks).

The transformation algorithm (minimum error), the maximum transformation error, the minimum grades for which the transformation will be carried out (at least 4) are established. The maximum transformation error should not exceed 3cm.

If the transformation is carried out according to these requirements, then a window is automatically displayed (Fig. 5), which shows the transformation results. The first column is the names of marks in the scanner coordinate system, the second is the names of these marks in the coordinate system adopted at the object of work.

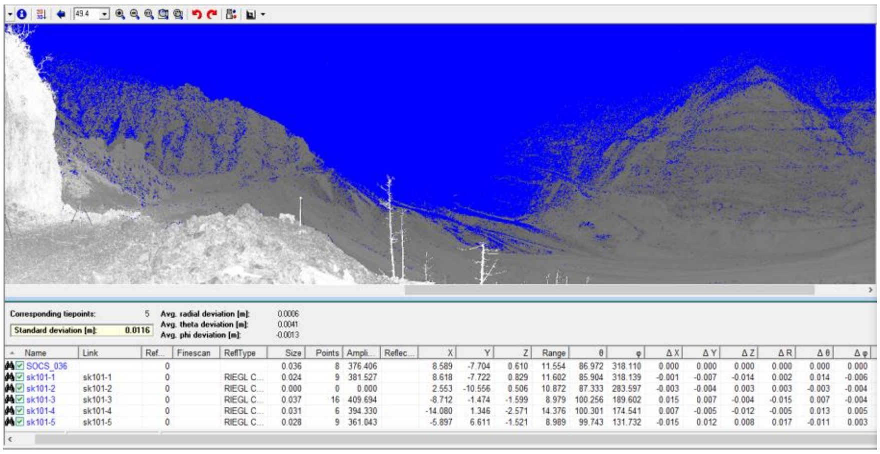


Figure: 5. Window for viewing transformation results.

The largest number of stamps was used at the facility. If there is a surplus of grades, it is possible, by turning off the ones that have the greatest negative impact, to reduce transformation errors to a minimum.

The result of the transformation process is scans (point clouds), each point of which is defined in a single coordinate system. Then the scans (point clouds) are combined into a single point cloud throughout the object.

The transformed point clouds in their essence are already a digital model having real 3D coordinates, in the accepted conditional coordinate system of the project (Fig. 6-10).

The terrain model, built during post-processing in MicroStation, has an average density of 9 points per 1 m^2. This density allows us to have a full understanding of the actual geometric parameters of the relief elements.

Further processing is carried out in the AutoCAD Civil 3D environment and consists in three-dimensional modeling of the characteristic relief contours.

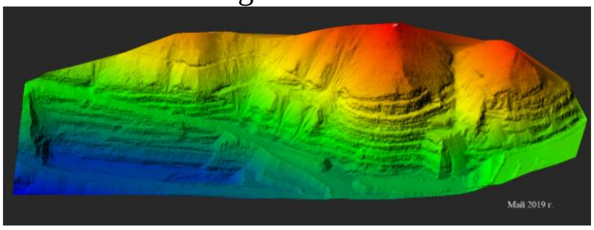


Fig. 6. 3D model of the cut side for May 2019

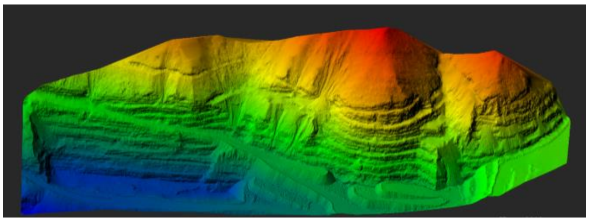


Fig. 7. 3D model of the cut side for October 2019

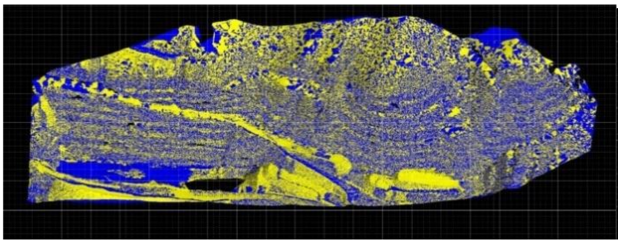


Fig. 8. Comparison of 3D models of the cut flank on two surfaces View - 1: blue color - May, yellow color - October

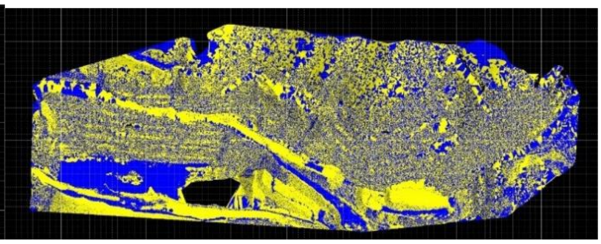


Fig. 9. Comparison of 3D models of the cut flank. View - 2: blue color - May, yellow color - October

Fig. 10. Photo report of the cut side

Based on the monitoring results, a comparative analysis was carried out to determine the deformations and displacements of the sides of the Kharanutsky coal mine, according to the data of ground laser scanning for various periods, which was carried out in the RISCAN PRO environment (Fig. 11-12). Digital elevation models (DEM) were built based on two observation cycles. DEM according to observations of the first cycle is plotted in blue, the second cycle - in yellow. The comparison results show the places where deformations and displacements are detected.

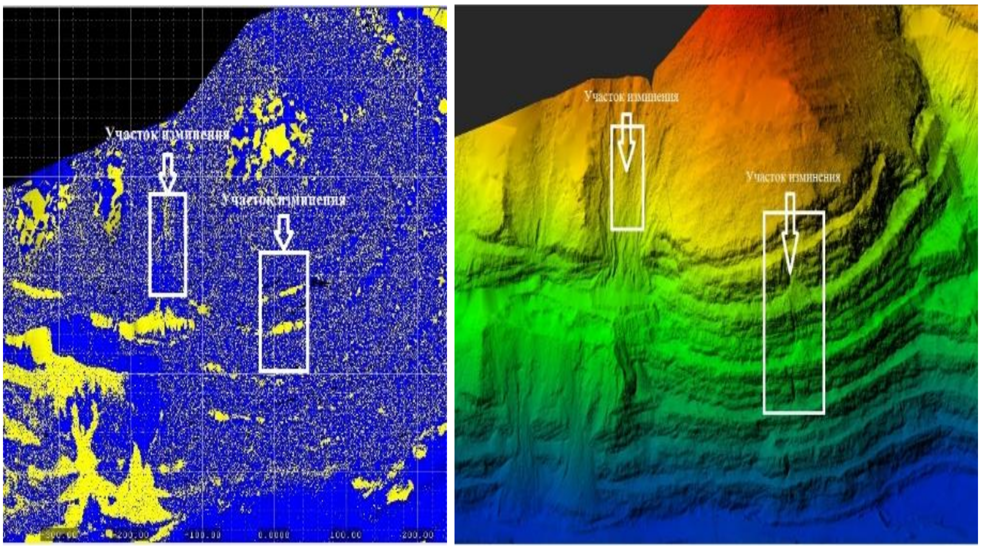


Fig. 11. Section of the Kharanutskiy open-cut mine (indicating displacements and deformations).

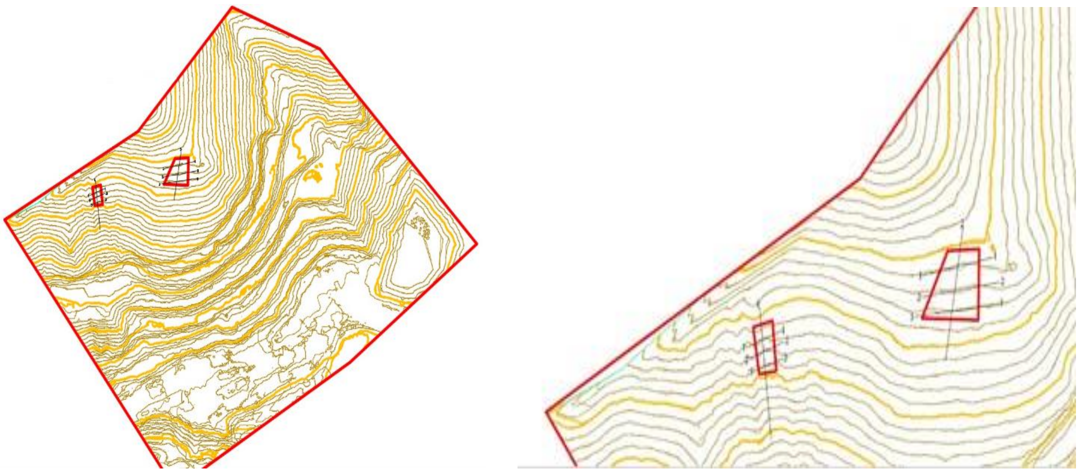
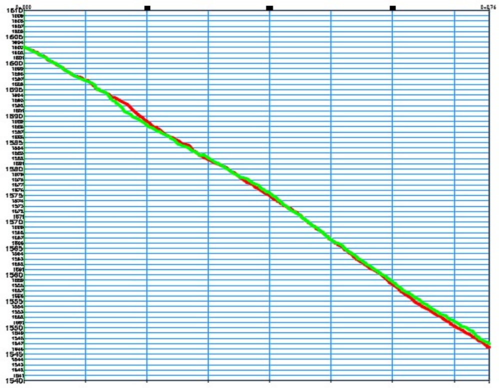
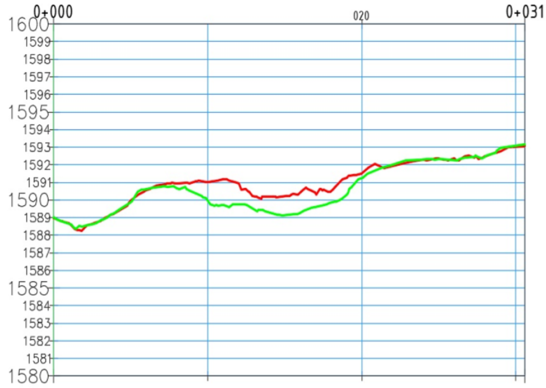


Fig. 12. Plot of recorded talus according to the results of 2 observation cycles.

Below are the graphs built according to the data in Fig. 12, which shows the dynamics of the changes in the state of the working side of the section for two cycles of observations and the displacements detected (red - 1 cycle, green - 2 cycle) (Fig. 13-14).





Conclusion. Thus, the results of observations of deformation processes at the Kharanutskiy coal mine show that no significant changes are observed on the sides and ledges of the section. No displacement of the rock mass of a landslide nature is observed according to the results of the 2nd measurement cycle, however, talus was recorded in some parts of the section. Some changes recorded in the places of mining operations are due to the excavation of the rock mass and drilling and blasting operations. According to observations of deformations and displacements of the sides of the Kharanutsky coal mine, it can be concluded that at this stage no critical displacements have been identified, despite the places where small rockslides are manifested. Further observations are recommended.

The results of laser scanning confirm the conclusions drawn from the results of satellite observations on the control points and the survey of the sides of the section. To carry out work on ground-based laser scanning along the strike of the entire section, a special-purpose network (base stations) was created with a high accuracy of mutual position in the WGS-84 coordinate system.

Conducting sequential series of laser scanning and GPS surveying of the section with subsequent analysis of the results makes it possible to solve the following set of tasks: to carry out remote areal monitoring of the propagation of deformations of the sides with the identification of areas where surface subsidence occurs (landslide areas); determine the volumes of deforming masses; identify trends in the course of the deformation process; delineate hazardous areas; assign design sections to assess the stability of the pit walls; operational surveying accounting of the volume of mining operations performed.

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