Digital survey in studying open pit wall deformations

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Abstract. The article highlights the topical problem of increasing efficiency of survey during monitoring of rock and earth surface displacement when studying various kinds of deformations caused by mining. To settle the problem, new methods based on use of new devices, programmes and technologies are applied along with traditional ones. The object of the study is an open-pit slide. As it is dangerous to stay on, remote monitoring methods become the most efficient ones, digital photogrammetric survey being one of them. Digital survey methods are being improved along with development of more sophisticated devices and software. The article deals with the method of open-pit slide monitoring involving digital ground survey with the Canon EOS1200D camera. Camera station reference was performed on the basis of GPS data and marker reference – by intersections.

1 Introduction

Open pits and dumps are important objects of the technological process at surface mining of useful mineral deposits. They are complicated engineering constructions requiring both precise fulfilment of design solutions and constant control of their state even after the active stage of their building or formation due to such factors as geological and hydrogeological characteristics, geomechanical processes etc. These factors result in deformations of walls and bench slopes of open pits and dumps causing rock caving, slides, settlements and other kinds of deformation. Each object is characterized by specific deformation kinds. One kind of deformation is often a sign of another, more serious one that can cause financial losses and sometimes loss of life. That is why; geodesy and surveying are important stages of deformation monitoring and, as a rule, are conducted by surveying services of open pits or mines [1 – 4].

At underground mining most engineering facilities are located underground and undergo constant control and monitoring. Underground mines apply various mining systems that lead to increase of stability of underground facilities [5 – 7]. The suggested highly efficient mining systems with bulk caving and open stope [8 – 10] enable increased stability of underground facilities and create a displacement zone on the surface of over 50 ha. In [11 – 14] the authors suggest various technological methods to decrease the rock

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displacement area, room-and pillar methods and underground concentration with tailings discharge into dead rooms being among them. Conducted laboratory studies [15 – 18] confirm the possibility of using resource-saving technologies, while the cost of production increases 1.2 – 1.5 times. So, in order to decrease the surface displacement zone, mining enterprises place permanent dumps in it.

Great mined mass volumes of millions of m^3 and huge areas occupied by open pits and dumps create certain difficulties for monitoring deformation processes at such objects and sometimes make it impossible to investigate large areas with the required accuracy [19 – 24]. Solution of this problem is dealt with by many scientists [25 – 28]. No doubt, modern methods (e.g. interferometric ones determining deformations with accuracy of fractions of a millimeter on huge areas) should also be applied but this equipment is rather expensive and few enterprises of Ukraine can afford them.

2 Methods

Krivbass mining enterprises apply the classical methods of monitoring rock and surface displacement which comply with regulations of instructions [29 – 35]. The main method of determining deformations is the one using profile lines. The method provides objective and accurate results of determining the state of an object in the place where benchmarks of the profile line are located. The place for a profile line is selected on the basis of calculations and area reconnaissance. Besides, places for profile lines are chosen on the basis of the results of visual examinations of the area on problem sites with fissures, slides and so on.

The profile line method involves presence of people on the object and that is why it is not applicable on potentially hazardous sites. One of such objects where people are impermissible is an open-pit slide. In such conditions the remote sensing technique is the most reasonable method, digital ground survey being one of them.

3 Results and Discussions

For digital survey of the open-pit slide a digital *Canon EOS 1200D* camera was used. It is a low-price amateur reflex digital camera. Its disadvantages are lack of stabilization and low image quality in poor lighting. The former is completely compensated for by use of a tripod, the latter – by standard requirements to aerial and ground survey (choosing the most favourable weather conditions). The main parameters of the camera which are important for surveying for monitoring and mapping are the following.

The camera sensor is 22.3×14.9 mm (5184×3456 pixels) that makes 18.7 million of pixels of which 18.0 million pixels are effective. Further improvement of detail, precision and quality of photography can be achieved through application of the latest full-frame sensors with 30 to 45 megapixels. Light sensitivity makes from 100 to 6400.

The 9-point AF (cross-type AF point at center) has some disadvantages. Most images filtered by quality are results of AF system “misses” or image blurring. At that, on the whole, results of manual focus (MF) are worse than those of autofocus.

Photographing was performed on the principle “better excessive data than insufficient data”, so filtered low quality images did not impact their necessary quantity. Also, it should be noted that photographing was performed under unfavourable conditions: unsteady lighting, air temperature of +5 ºC, proximity to working mechanisms, atmospheric precipitation. Such conditions are common for open pits and dumps. So, statistics on photography are revealing, especially for handheld supported by a geodetic tripod. The resulting 239 images from 9 camera stations have the quality: min 0.25, max 0.85, average 0.72, statistical deviation 0.11.

The *Agisoft Metashape Professional* software was used to assess the images and 12 of them (5% of the total number) were rejected as their quality was below 0.5. Fig. 1 presents the bar chart of frequency of obtaining images of various quality. Frequency is indicated on the vertical axis, quality – on the horizontal one.

Main reasons for low quality images are blurring and autofocus errors. The viewfinder characteristic is an important parameter as it helps to choose boundaries for each image to cover the maximum number of markers. When regular used, the shutter should ensure long and reliable work that is usually provided by low price reflex cameras, not to mention professional ones with shutters operating during the period sufficient for taking several thousands of pictures.

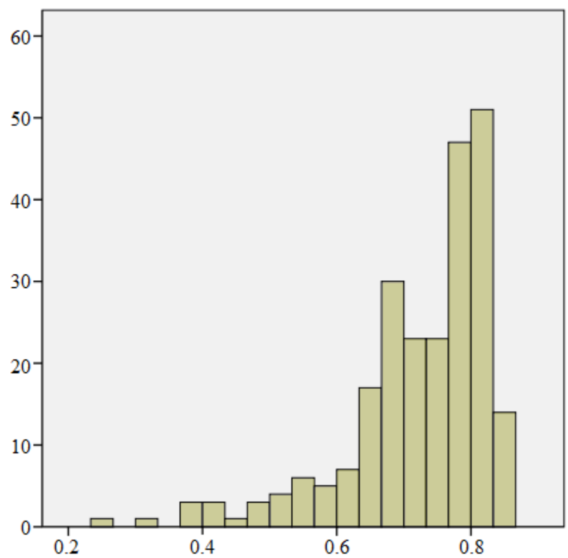

Fig. 1. Frequency of various quality images occurrence.

For photographing, *Canon Lens EF 50mm 1:1.8 II* was used in the *Canon EOS 1200D* digital camera. The lens has the fixed focus length of 50 mm and no Zoom, thus providing minimum distortion and brightness of images. Use of lenses with Zoom and smaller focus length to increase the coverage angle would seem to be more beneficial but this would result in greater distortion. Noise was reduced by limiting ISO to 400. Further quality enhancement can be reached by fixing the digital camera to a station.

At present, application of GNSS equipment is the most efficient marker reference method at aerial and ground surveying of areas including open pit mining operations. However, GNSS receivers cannot be used in studying part of the open pit with a slide as it is hazardous for the personnel. In this case, to coordinate markers, it is reasonable to use a reflectionless stantion or intersections. Use of the reflectionless stantion is complicated due to large distances to the opposite wall. Here, devices with the reflectionless mode from 1200 to 1500 m should be used. These requirements consider geological rocks that absorb rays. That means that reflectionless station certificate parameters should be decreased 1.5 – 2.0 – fold. The reflectionless mode facilitates error decrease, in determining markers coordinates. As the *Sokkia SET630R* station was used, it was reasonable to determine marker coordinates on the slide area by intersections.

Camera station references were performed from points of the surveying reference network by the method of quick-still photography. Mean-square errors of determining plane coordinates and heights of markers and monitoring points (camera stations) did not exceed

9 mm in plane and 9 mm in height. From the experience, accuracy of 10 – 30 cm, and sometimes more, is enough to determine coordinates of camera stations. Table 1 presents coordinate increments and results of assessment of determination accuracy for plane coordinates m_{XY} and heights m_Z of camera stations.

Table 1. Results of assessing determination accuracy for camera station coordinates.

Name	ΔX, m	ΔY, m	ΔX, m	m_{XY}, m	m_Z, m
111-Base	-794.524	-358.274	10.872	0.001	0.002
222-Base	-676.433	-400.420	10.021	0.001	0.002
333-Base	-553.752	-446.818	14.262	0.001	0.002
444-Base	-307.151	-508.827	16.338	0.001	0.001
Base-p1	239.769	498.611	-15.944	0.002	0.003
Base-p2	310.290	509.124	-16.147	0.002	0.003
Base-p3	554.421	446.687	-14.437	0.003	0.004
Base-p4	612.416	422.613	-11.458	0.004	0.006
Base-p5	677.468	400.776	-10.157	0.002	0.002
Base-p6	706.293	391.443	-9.621	0.006	0.007
Base-p7	783.188	363.459	-10.791	0.007	0.008
Base-p9	891.304	237.128	-13.634	0.025	0.039
Base-p10	948.095	207.252	-13.205	0.003	0.005

Markers coordinates were determined by applying the intersections method from three points with coordinates determined by a GPS. Points 4, 11, 13, 14 and 15 were rejected as mean-square errors of determining their coordinates made 0.3 m. After rejecting rough data, the minimum and maximum errors of determining plane coordinates of the points made 0.11 m and 0.26 m respectively and their heights 0.09 m and 0.13 m respectively (Table 2).

Table 2. Results of assessing determination accuracy for control coordinates.

Point number	m_{XYZ}, m	m_X, m	m_Y, m	m_Z, m
1	0.175	0.055	0.166	0.103
2	0.178	0.057	0.169	0.103
3	0.170	0.054	0.161	0.101
5	0.129	0.033	0.125	0.093
6	0.168	0.037	0.164	0.107
7	0.263	0.046	0.259	0.136
8	0.170	0.063	0.158	0.110
9	0.232	0.046	0.227	0.128
10	0.128	0.037	0.123	0.095
12	0.156	0.036	0.151	0.104
16	0.241	0.075	0.229	0.122
17	0.192	0.065	0.181	0.107
19	0.118	0.037	0.112	0.091

Analysis of the data enables the conclusion that great errors at points 4, 11, 13, 14 and 15 resulted from the fact that their coordinates were determined in different ways from different camera stations and due to this their outlines differed. The optimal scenario would be use of crosses, surveying rods or other forms of marked points but due to impossibility of people staying on the slide, stones, sleepers and other easily identifiable objects in the area were used with this purpose. It should be taken into consideration that accuracy of sighting on selected objects is worse than on specially made marks. The accuracy can be increased through use of reflectionless stations with the reflectionless mode length of up to 1500 m.

Forms of geometric constructions are an important factor impacting accuracy of coordinates determination. Stations which are used not only for photography but also for determining marker coordinates are located on boundaries of the photo base. Stations should be located at the distance equal to the calculated value of the photo base (at the maximum distance from each other) considering technological transport work, a geometrical form of the open pit and safety requirements.

During subsequent photography series coordinates of the camera stations were determined with the help of the *GPS Receiver GP-E2* the error of which is 6 – 8 m but this is quite sufficient for surveying using markers. Use of *GPS Receiver GP-E2* with *EOS 5D Mark III* and *EOS-1D X* for ground surveying is promising and, using a digital compass, enables determining additionally the magnetic azimuth value. As *Canon EOS 1200D* does not support this device via the hot shoe, the coordinates were recorded into a special file and then the *GPS Receiver GP-E2* software rewrote them into the image file.

Several programmes can perform photogrammetric processing of images, *Agisoft Metashape Professional* and *Pix4d* being main ones. Each programme has its own advantages. It should be noted that *Pix4d* has a demo period enabling decisions on the software for processing. Images were processed by the two programmes. The obtained digital models were practically similar. However, if it is necessary to create certain elements of the open pit (e.g. the top edge, the bottom edge, etc.), *Pix4d* is preferable as the 3D-interface of *Agisoft Metashape* is not very convenient.

When studying sliding at open pits, less attention is paid to accuracy of edges location than to the condition of the massif as a whole. The main task is to obtain a so called “extraction-fill” map of the object. On the basis of the obtained material the open-pit condition was analyzed. Availability of clay and loam facilitate appearance of up to 0.8 m high vegetation on the slide during summer and autumn that badly influences the object monitoring accuracy. So, to enhance accuracy, monitoring should be carried out in winter, early spring or late autumn. Within the open-pit slide study surveys were conducted on the 17 of February, 06 of April and 05 of October, 2018. During the second survey sessions a considerably greater number of markers were used but the surveyed territory was greater as well and included permanent open pit walls and working sites of benches.

Figs. 2 and 3 present charts of control points as of the dates of the second and third surveys. The points are represented by ovals the colour of which characterizes the height error and its orientation shows the error direction in plane. The oval size shows the error value, but in Figs. 2 and 3 it is increased equally for all the points.

Table 3 presents mean-square errors of determining coordinates of points on the slide.

The model of the part of the open pit under study is given in Fig. 4a (as of 06 April, 2018) and Fig. 4c (as of 05 October, 2018). Values of deformations occurred between the survey sessions of 17 February, 2018 and 06 April, 2018 are given in Fig. 4b, between the sessions of 17 February, 2018 and 05 October, 2018 – in Fig. 4d. Values of deformations occurred between the first and the second sessions are insignificant and characterized mainly as filtration deformations caused by rock mass falls or flattening of certain sites. Deformation values did not exceed 0.4 m.

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Table 3. Mean-square errors of determining coordinates of points on the slide.

Point number	m_X, cm	m_Y, cm	m_Z, cm	m_{XYZ}, cm	m_{XYZ}, pix
1	8.023	12.710	8.361	17.200	1.683
2	-0.398	-0.978	-0.317	1.102	0.924
3	-18.443	-0.974	0.005	18.469	1.412
4	5.554	-0.472	-3.420	6.540	0.862
5	12.935	11.755	-2.585	17.669	0.771
6	-4.726	2.503	-1.251	5.492	0.399
7	-12.423	4.274	0.635	13.153	0.502
8	-5.229	-6.862	3.758	9.410	0.591
9	-6.579	-2.352	-2.110	7.299	1.073
10	-24.998	-2.356	0.348	25.111	1.426
11	7.778	-6.206	-17.404	20.048	1.014
12	8.355	2.488	-4.592	9.853	0.895
13	1.195	-2.276	0.490	2.617	0.389
14	4.580	0.683	-2.660	5.341	1.390
15	-1.990	-6.177	-17.565	18.726	0.774
16	-16.121	-10.057	27.786	33.662	13.359
17	-5.311	-2.553	20.698	21.521	1.969
18	1.724	0.851	2.229	2.944	0.640
19	-15.136	14.401	2.859	21.087	0.985
20	3.162	-2.908	6.762	8.011	0.686
22	16.038	-6.174	7.052	18.576	0.420
23	-8.373	-4.829	-7.516	12.244	0.835
23	4.643	4.577	-0.376	6.530	0.604
24	11.591	-0.166	4.595	12.470	0.345
25	4.208	0.393	-5.844	7.212	0.617
26	6.680	8.980	7.078	13.243	0.336
27	1.217	10.892	-6.485	12.735	0.452
29	9.985	5.738	3.612	12.070	1.458
30	-1.332	-13.559	-4.947	14.494	0.720
30	13.024	-7.185	-4.111	15.432	0.748
30	10.189	-5.550	-4.159	12.325	0.597
33	-12.091	-1.779	2.782	12.534	0.561

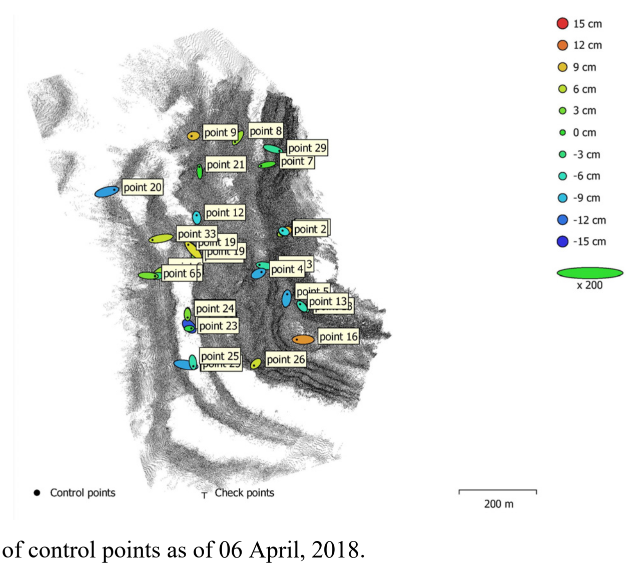

Fig. 2. Location of control points as of 06 April, 2018.

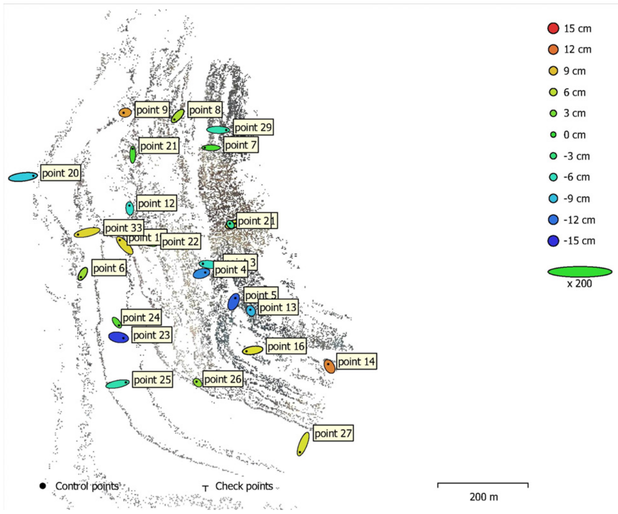

Fig. 3. Location of control points as of 05 October, 2018.

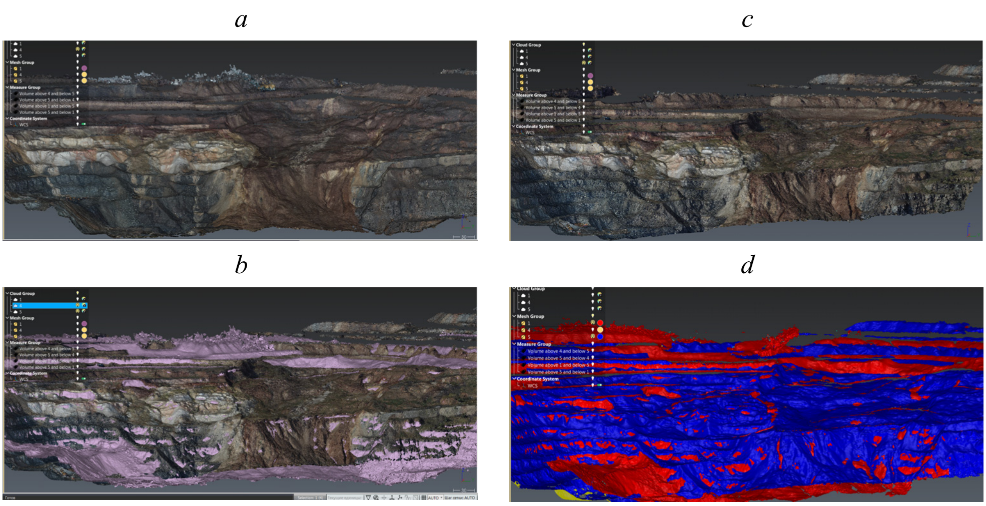

Fig. 4. The model of the part of the open pit (a) with deformations as of 06 April 2018 (b); the model of the part of the open pit (c) with deformations as of 05 October 2018 (d).

Fig. 5. presents distribution of deformation values on the slide area. The deformations occurred between the first and the second surveys (17 February, 2018 and 12 April, 2018).

The red colour of various intensity describes value of mark decreases, the blue one, on the opposite, shows increases (rock mass piles etc.). Fig. 5b shows distribution of deformations occurred between the second and the third surveys, Fig. 5c – between the first and the third surveys.

Deformations of the second period (06 April, 2018 – 05 October, 2018) are of the same origin as those of the previous period, but their values are much greater due to slide response operations and emergence of the ground water source impregnating the slide body with moisture. Deformations at some points exceed 1 – 2 m.

To record the *Exif* data, *Exif Pilot* was used. In addition, data on the camera station (its latitude, longitude and altitude) was introduced into the image file. Among the wide range of software for transferring information from a GPD coordinates file to a digital image file, *Lightroom* of *Adobe* deserves special mentioning.

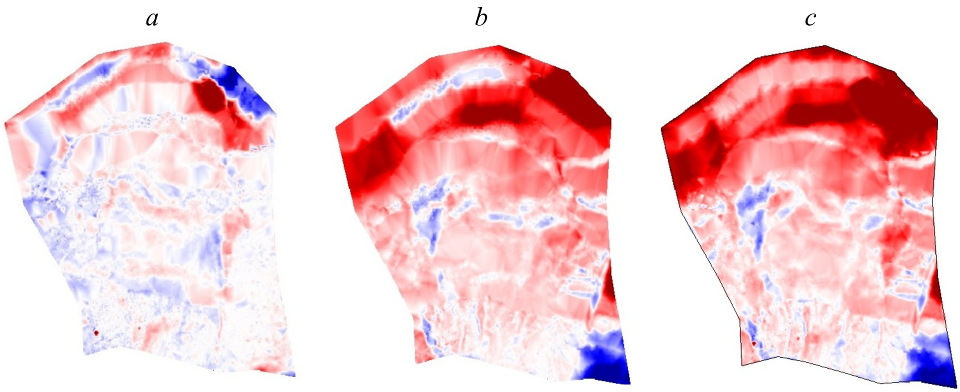

Fig. 5. Distribution of values of deformations occurred between the survey sessions: a (from 17 February, 2018 till 12 April, 2018); b (from 12 April, 2018 till 05 October, 2018); c (from 17 February, 2018 till 05 October, 2018).

The second and third survey sessions were conducted with the help of *GPS Receiver GP-E2* supplied with *GPS Log File Utility*. Description of the *GPS Receiver GP-E2* software mentions that the receiver is to be viewed in the menu of the GPS-device to *EOS1200D*. However, in practice, the camera does not see it, so the GPS log-file was exported direct into the image file.

Every survey is characterized by certain parameters: the number of camera stations, control points, distance from the station to the object etc. Fig. 6 presents locations of the stations and the surveyed area as of 06 April, 2018. Colours correspond to the number of images taken of this or that area of the slide. Surveys of 06 April, 2018 are characterized by the following: 48 qualitative images taken; distance to the object of 664 m; 32114 change points; resolution of 5.68 cm/pixel.

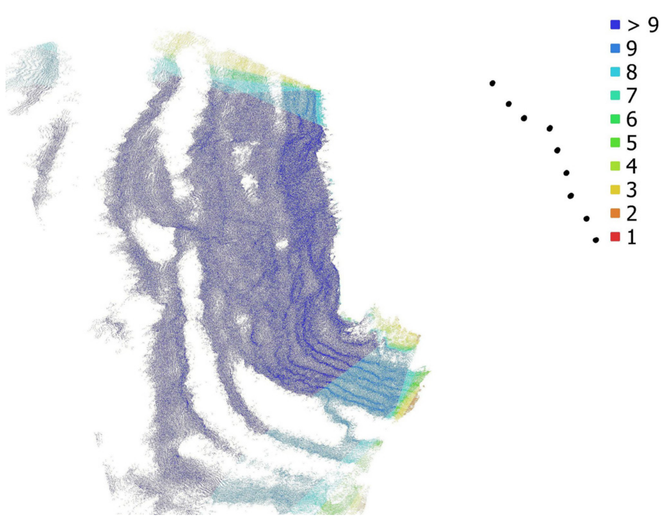

Fig. 6. Location of camera stations and photography coverage of the area (number of images) in colour.

The study conducted resulted in determining the fact that to enhance the survey quality, degree of detail of images, nearly 80% of the photographed territory is processed by images from nine or more camera stations. Complicated geometrical forms of bench elements, availability of a great number of other open pit objects (roads, power transmission lines, ramps etc.) are important factors impacting increase of the image number. Minimum required four camera stations at the site do not provide the required quality of processing all open pit elements.

Modern drones are equipped with digital cameras with small focus lengths and large coverage angles. Ground surveying by such a camera can decrease the number of images but this requires determining exact elements of inner orientation, especially distortion. Such approach is partially proved. It is a compromise between productivity and accuracy, flying height and energy spent on reaching the designed survey height and maximum loads on a drone or wing. Ground surveying neutralizes some of these factors but the survey coverage angle problem still remains unsettled.

The important issue to be studied is the problem of enhanced accuracy of determining markers on inaccessible sites. Commonly, aerial or ground survey uses GNSS-equipment or reflectionless stations for this purpose. However, both methods cannot be applied to surveying such objects as open-pit slides. Thus, the study resulted in the conclusion of reasonability of using classical photogrammetric methods for processing images. Previously, the authors used normal and equally deviated surveying methods with the “improved phototheodolite” (combination of a station and a digital camera). Certainly, this method involved significant labor expenditures and a great amount of preparatory and field work that differs from flexible and operational drone surveying.

4 Conclusions

The suggested method of geodetic and mine surveying work on monitoring slides in open pits has a number of advantages: no people in potentially hazardous places – slide zones and other areas subject to deformations; operations are performed within short periods of time; visual graphic representation of results; accuracy of monitoring results.

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