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Research

METHODOLOGY FOR EFFECTIVE DETERMINATION OF ROCK JOINTING IN CALCULATION OF OPEN PIT EDGES

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ABSTRACT

This paper is intended to increase the reliability of measuring the stability of open pit edges by developing a methodology for remote determination of rock jointing. The study employed a number of methods: analysis and summarization of results of previous studies, including those presented in regulatory and methodological documents; instrumental studies in field conditions, mathematical processing of experimental data results, computer modeling of stress strain behavior of the near-edge massif. The paper proposes the scheme to account for rock jointing by using digital photo survey in order to specify the stability parameters of edges, with the remote method to study jointing tested at the Novosergeyevskiy and Pechurki open pits. The practical value consists in developing calculation methods for stability of open pit edges by accounting for rock jointing. The obtained results can be used at design mining companies, educational institutions and at open pits (quarries), as well as at specialized organizations studying rock jointing properties.

INTRODUCTION

The modern stage of the development of mining technologies by employing open pit methods is described by significant extraction depths that may be several hundred meters, which increases the requirements to ensuring pit edge stability. Landslide deformations of benches cause great financial losses needed to eliminate the consequences of emergencies, but what is most important, they may result in casualties, and, in addition, a justified increase in edge angle, even within a single degree, causes substantial savings in mining works.

Irrespective of the significant achievements in assessing the stability of pit edge, no methodologies have been developed so far that would comprehensively account for the massif jointing and its influence on the edge safety factor, and the conventional methodology to study the jointing at the pit (the method of direct field measurements consisting in the calculation of the number of fractures per length unit, or in measuring all distances between joints in the area of study by using a measure tape (Takranov, 1972; Takranov, *et al*., 1973) fails to meet the requirements of the efficiency, information value and safety, and is related to risk for life and health of the performer, which reduces the investigation efficiency.

The significant influence of jointing on the rock strength has been highlighted by many authors (Mosinets and Abramov, 1982; Nenasheva, *et al*., 2005; Ruppeneit, 1975). There are methods for remote determination of jointing by using photographic images (Kryukov, *et al*., 1973; Korablev, 1973; Kurganov, *et al*., 1991). As early as in 1960, Baron (Baron, 1960) proposed taking preliminary pictures of the rock surface in order to find out oversize material through images; this method was called photoplanimetry.

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Various authors (Viktorov, *et al*., 2007; Mechnikov, 2005) also describe methods of remote investigation, but those do not meet the requirements of time, i.e. most methods and instruments can currently be deemed obsolete, and photogrammetric methods proposed by some authors suggest using rare equipment (field phototheodolites, stereogram cameras, etc.), and the methodologies to study the structure of rock massif apparently fall behind the scientific progress, production of photo digital and computer equipment and technologies. In remote investigation by using such methods, a performer has to make measurements according to printed photo images manually and reduce these measurements to actual values taking into account the image scale.

In one of the most recent papers, Tutakova (Tutakova, 2007) proposes the use of MICROMINE GIS for modeling and calculations. However, building 3D models, which has become very popular recently, is a time-consuming task, and displaying block and joint structure of a rock massif in space carries superfluous information. We believe that to obtain current geological information for a specific block, it is sufficient to study a 2D image. 3D modeling is certainly a perspective and modern trend in engineering, but we think that it only gives additional visualization when solving this specific task. The works by Potresov et al. (Potresov and Lvov, 2003) describe the method to automatically determine jointing consisting in seeking for local minimums of brightness. The recognition methodology is based on the assumption that all joints in the image are represented in darker tones and the rock surface of the massif is represented by lighter ones. As a result, shadows are taken for local minimums where joints should be located, e.g., joints are not sufficiently segregated from the background (from the objects that are neither fractures nor shadows).

METHODS

The primary task of the study is to develop a system for efficient determination of jointing in a near-edge massif through digital photo imaging and computer processing of results in order to obtain output parameters to calculate the stability of a specific edge by using modern software systems. In this manner, it has been planned to achieve operational efficiency in assessing the stability of benches at various stages of mining taking into account specified physical and mechanical properties.

The study employed a number of methods: analysis and summarization of results of previous studies, including those presented in regulatory and methodological documents; instrumental studies in field conditions, mathematical processing of experimental data results, computer modeling of stress strain behavior of the near-edge massif.

The remote study of the rock massif has several advantages as compared to the conventional methods of direct visual observations and sketches: a photo image can be easily enlarged, reduced to a specific scale, transformed, multiplied, which allows demonstrating the photographed phenomenon to a high number of remotely located viewers, and the image allows reasonably recording a large number of objects for a short period of time.

The efficiency and informativity of works is also increased by the expansion of the area of study-unlike conventional measurements by a measure tape, when works are carried out within the performer's height, a photo image survey allows studying the bench slope in full, irrespective of its height.

During a photo survey in this study, the camera was placed almost parallel to the section of the bench to be photographed. Photo imaging can be carried out from a non-operating edge of the pit or from the bottom of the photographed bench if the distances allow locating the entire height of the object within a frame. Photo imaging from a non-operating edge can be called optimal when the image plane parallelism and slope plane of the photographed bench are observed. During photo imaging, it is necessary to use a photographic tripod in order to achieve parallelism between the image and the bench slope; besides, it is required to take images with overlapping and panning in order to eliminate distortions along the image edges. NIKON D70s camera was used for photo survey.

To ensure the accuracy of survey, it is necessary to observe parallelism between the image and the slope, so tripods with tilting and rotating mechanisms are used and the camera is adjusted for a specific angle. Most favorable conditions for photo documentation are described in the thesis. To scale the image within the area to be represented, a rail, zigzag rule or any other scaling device is placed.

The resulted images are recommended to be metrically processed in an environment of popular software frequently used by mining companies: AutoCad or MapInfoProfessional, which are used to measure linear distances between fractures. The method accuracy is generally influenced by possible mistakes in the survey process (out-of-parallelism between the image and the bench slope, too small survey distance) and errors in decoding that mainly depend on survey conditions, quality of photo materials and decoding skills.

To prove the validity of studying photo images for quantitative assessment of rock massif jointing, the results of traditional manual field measurements were compared with the data obtained through studying photo images of the same sites. The distances between fractures in photo images were measured for five sites in Ekibastuz and Mezhdurechensk (Takranov and Pavlov, 1996; Takranov and Zhilin, 2006), Pechurki, and Novosergeyevskiy pits. By analyzing field measurements of jointing parameters in pit bench slopes, a conclusion can be made on the validity of using digital photo surveys in order to study jointing, which is provided by high convergence of results obtained by two different methods, i.e. photo survey and computer processing of its results yields comprehensive information on the block and joint structure of the rock massif.

It is known that one of the primary factors affecting the stability of bench slopes and pit edges is physical and mechanical parameters of the rock massif (Baklashovm, 2004). The accuracy of stability measurements in pit slopes depends on the reliability of finding out their properties. The primary physical and mechanical parameters of the massif used in slope stability calculations include the angle of internal friction and adhesion. However, if the angle of internal friction measured during laboratory tests of rocks can be adopted to describe internal friction in the massif with sufficient reliability, the massif adhesion significantly differs from the values obtained during sample testing.

The fractured massif strength is greatly affected by the factor of jointing intensity that is expressed by the number of fractures in a length unit $K_1=K'(H/h)^{-0.6}$.

where H/h=jointing intensity (number of fractures per 1 m), K_1=massif adhesion, K=sample adhesion. K_1 to K relation represents a structural weakening coefficient (Borsch-Komponiets, 1968).

According to this formula obtained by Borsch-Kompaniyets, it is possible to obtain structural weakening coefficients for the rocks of various degree of jointing. The formulas of Fisenko (Fisenko, 1998) and Borsch-Kompaniyets for this specific edge showed identical results; therefore, the simplified Borsch-Kompaniyets formula was used without variable tabular coefficients.

The fracturing of a rock massif greatly affects the pit edge stability. Laboratory results for rocks can be used when solving practical challenges only after finding out the structural weakening coefficient. In our opinion, the structural weakening coefficient of rocks can be determined by using photo images of bench slopes in order to solve the issue of edge stability by using specified indicators of rock strength.

Mining graphical documentation is taken as a basis for modeling (layout and geological profiles), and photo survey allows specifying the geological structure by outcroppings and bench jointing, since these parameters can be used when calculating the stability of pit edges with respect to the structural weakening coefficient.

The above approach was implemented through the example of the Novosergeyevskiy coal pit (UK Kuzbassrazrezugol OJSC). The Novosergeyevskiy pit edge is made up of sandstones, aleurolites and argillitea. This area was photo surveyed to identify the jointing intensity for each bench of the represented pit edge (Sannikova, 2011; Sannikova, 2013).

RESULTS

By studying photo images using the computer modeling methods, we obtain the results for the intensity of bench slope fracturing. Being aware of adhesion found out at the site during laboratory sample testing, we can introduce a structural weakening coefficient expressed by using the Borsch-Kompaniyets formula through the jointing intensity. In this manner, we go from strength parameters in a sample to adhesion in the massif. In what follows, these data are used in modeling of stress-strain behavior of the near-edge massif and in calculating the safety coefficient of the edge. Sixty models of the same configuration but different jointing and made up of different rocks were modeled. For each model, safety coefficients were calculated.

DUSCUSSION OF RESULTS

The works were discussed at the 5th International Scientific and Practical Conference in AGH (Krakov, 2011), the International Scientific and Practical Conference "Engineering and Technology: New Development Perspectives" (Moscow, 2013), the XXIst International Conference of Students, Postgraduates and Young Scientists "Lomonosov" (Moscow, MSU, 2014), the XVIth International Scientific and Practical Conference "Fundamental and Applied Studies in the Modern World" (Saint Petersburg, 2016) and at a number of other conferences.

CONCLUSION

The proposed process comprising the collection and processing of information on massif fracturing and its further accounting in modeling stress-strain behavior of the near-edge massif and in calculating the safety coefficient of the edge in the conditions of open pit mining of mineral deposits increases the safety and efficiency of mining.

The authors personally contributed to the development of the common study methodology, directly participated in obtaining initial data and testing the study results, processing and interpretation of initial data, analysis of scientific and technical literature, developing the image processing methodology and preparing publications.

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