Detection and Measurement of Cracks in Rock Massifs by Means of Ground Laser Scanning

Kremena Stereva 1

1 The University of Mining and Geology “St. Ivan Rilski”, Studentski Grad, “prof. Boyan Kamenov” Street, 1700 Sofia, Bulgaria
k.shtereva@mgu.bg

Abstract. The analysis of the cracking of the rock massifs is an important stage in the process of their characterization, as this largely determines their mechanical behavior. This is the main reason the mining engineers, who are engaged with the analysis of rock massifs, to require a most detailed and reliable study of the cracks that have arisen in them. Metric characteristics, such as the direction and angle of collapse of the cracks, roughness and average distances between the individual cracks, are extremely important for the study of the structural disturbance of the massif. In the process of the metrics forming of these characteristics, a few of methods of measurement and graphical representation, different in nature and technological features, have become necessary.

Through these traditional methods, it is very often not possible to obtain adequate quantitative data for the complete geomechanical characteristics of the rock mass and for the analysis of the mechanisms for its instability. Here, the effectiveness of the ground laser scanning in the study of the structural disturbance (direction and angle of decay of the cracks) and the area cracking coefficient of the rock mass has been experimentally proved. Through this technology the research of the structural disturbance of the rock massifs acquires new quantitative and qualitative dimensions. On the basis of an extremely detailed 3D model, even of hard-to-reach sections of the rock massif, a realistic clustering of cracks and prerequisites for adequate determination of the area cracking coefficient of the massif are created. Moreover, ground-based laser scanning data are an indisputable source of valuable information about rock surface roughness.

For an object of the experiment, was selected part of a rock massif, which has well-developed, clearly visible cracks. The scan was performed, using a ground-based laser scanner “Scan Station 2” of the company “Leica”.

1. Introduction

If one could single out one modern technology among the many used in surveying practice today that contains a message to the surveyor of the future, it would undoubtedly be LIDAR or Light Detection and Ranging. This technology (better known as terrestrial laser scanning - TLS) is based on the joint use of conventional surveying equipment and global positioning systems in conjunction with laser distance meters. Such a combination creates preconditions for obtaining data sets for the surveyed surfaces as well as the objects located on them or in closed spaces. Depending on the specifics of the surveyed object, these data sets contain spatial information of millions, and sometimes billions, of high-density points per unit of area. This is the main reason why the TLS technology is used to solve a wide range of problems connected to the collection of geospatial data for topographic and engineering research purposes, as well as for the purposes of environmental studies, power generation and mining [1, 2].
The possibilities offered by the LIDAR technology for creating spatially positioned pseudo-continuous models on real surfaces make it extremely efficient for monitoring the exploitation and modelling of earth mass, as well as for complex research of rock mass [3]. However, the full application of this technology presupposes knowing it in detail in order to ensure the maximum reliability of the obtained results and the correctness of the ensuing conclusions and decisions. Each area of application of laser scanning has a specific impact on the final product of the scan - an impact determined by the physical and mechanical characteristics of the material that makes up the scanned object, the atmospheric parameters and climatic features during scanning.

2. Experimental research

Crack propagation analysis is an important step in the process of characterizing a rock mass, as it largely determines its mechanical behavior. This is the main reason why most mining engineers who deal with the analysis of rock mass require the most detailed and reliable study of cracks in the mass. Properties such as crack direction and angle of inclination, roughness and average distances between individual cracks are important for studying the structural disturbance of the rock mass [4, 7]. These characteristic properties of the rock mass can be assigned metric characteristics using various standard methods of measurement and graphical representations. The individual methods for manually identifying cracks have corresponding advantages and disadvantages, but they all have several common disadvantages:

- Incomplete or distorted data are presented due to sampling difficulties, e.g. choice of a sampling method, human bias, errors of the instrument used, etc. [8, 9]
- The risks to the personal safety of the sampler are often significant. It is not uncommon for field measurements to be made on existing slopes or during the operation of quarries, tunnels or mining works.
- Direct access to rock surfaces is often difficult or even impossible, which in itself compromises the entire research process.
- Methods for manually identifying cracks are time consuming and labour intensive and therefore costly [10, 11].

The possibilities for each specific implementation (or idea for implementation) of laser technology should be analyzed in detail in advance by preparing and carrying out appropriate experiments [5].

The object of the experiment, in this case, is a part of a rock mass which has well-propagated, clearly visible cracks. This rock slope was scanned using a Scan Station 2 terrestrial laser scanner of the Swiss company Leica.

1,474,143 pixels were scanned, with an average density of 2mm x 2mm (Figure 1). All scanned points were georeferenced in a predefined local coordinate system for the object by means of a network of geodetic points which was developed, measured and processed in advance.

The scanned image was processed using the 3D Reshaper specialized software. With its help, the scanned data were presented by means of a combination of contours, refractive lines, a surface mosaic, etc.

![Figure 1. 3D image of the entire point cloud of the scan (reduced points with an average density of 0.2cm x 0.2cm)]
Figure 2 shows the marked cracks in the rock mass.

Subsequently, the widths of the different cracks were measured twice: by means of a tape measure and on the digital model created after the scan (Fig. 4 and Fig. 5; Fig. 7 and Fig. 8). It can be seen that the crack widths determined in these two ways differ in the interval of 1÷4 mm.

Figure 2. The marked cracks in the rock mass

Figure 3. Crack location 1
Figure 4. Measuring the width of crack 1 with a tape measure (Measured width: 3cm)

Figure 5. Determination of crack width 1, from the digital model obtained by laser scanning data (Determined width from the digital model: 3.1cm)
Figure 6. Crack location 6

Figure 7. Measuring the width of crack 6 with a tape measure (Measured width: 4cm)
Figure 8. Determining crack width 6, from the digital model obtained from the laser scanning data
(Determined width from the digital model: 4.4 cm)

Based on the created digital model, the areas of the studied cracks were outlined in different colours,
with their lengths outlined in red (Figure 9).

Figure 9. created digital model, the areas of the studied cracks

3. Practical aspects and technological features in the implementation of the technology

The technology based on 3D laser scanning allows to capture in detail rock surfaces, access to which is
limited. The same can be said of access to sloping rocks and motorway embankments, railways or
surface mines, where conditions create work hazards. In addition, laser scanning in all its versions
creates the preconditions for a fast and accurate analysis of the system of cracks in the rock mass. The
most important advantage of applying this method is that a very high image density can be achieved by
varying the resolution, which can be changed in the range from 3 mm to 1 cm, depending on the
characteristics and size of the object. Therefore, a realistic 3D model of the studied object can be created,
characterized by very high resolution and accuracy. This, in turn, would allow, using various
interpolation techniques, to make an accurate reconstruction of the original rock surface in the form of
a 3D interpolated and smoothed surface. Using geometric analysis of this 3D surface, it would be
possible to observe the different groups (clusters) of cracks in the rock mass. With the help of appropriate clustering algorithms, the distinct groups of cracks could be delineated automatically and the average orientations of these identified groups could be calculated. Using a detailed 3D model, the distances between the individual cracks could be calculated very accurately.

In addition, by means of laser scanning, objects could be observed at a distance of several hundred meters if suitable conditions are available. In most real-life situations, however, distances to the observed object are in the range of 50 - 100 meters. Currently, a full scan, with a range of 360° and a resolution of 5mm, can be made in less than 4 minutes. Depending on the type of scanner, the resolution, and the size of the object, the speed of scanning may vary from a few minutes to half an hour.

However, it is not possible to extract complete information about the object based on the point cloud alone. The data from the point cloud can and should be visualized, which would give the user a very good visual idea of the scanned object. Finally, in order to analyze the surface of the object under survey in sufficient detail, the data from the point cloud must be reconstructed as a 3D model of the surface.

Laser scanning could also support other aspects of the geotechnical design. For example, carrying out an accurate study of the geometry of the slope, which, in turn, can be integrated with the study of other geometric elements such as drainage channels, road surface, all done in an environment of a properly selected CAD or GIS system.

The laser scanning data could create preconditions for extracting the roughness characteristics of each rock surface. The degree of roughness is clearly distinguishable in 3D models of a rock surface. As the different groups of cracks could be clearly identified, classified and separated, it would be possible to subject the surfaces of these cracks to a detailed statistical analysis.

The intensity of the reflected laser beam could also be used to determine the roughness of the rock surface. The rougher this surface, the more diffusely the laser beam will be reflected. However, the relationship between the roughness and the intensity of the beam could be too complex, as parameters such as the angle of inclination, humidity and mineralogy of the studied mass will also affect the level of intensity.

4. Conclusion

Apparently, terrestrial laser scanning creates incomparably greater opportunities for defining and implementing an effective monitoring program for quarrying. The volume of rock mass calculated by this technology is of very high accuracy and detail. The technology allows capturing hard-to-reach locations in an extremely short time, compared to classical methods. The application of terrestrial laser scanning for monitoring the operation of stone quarries and surface mines is a serious prerequisite for minimizing losses due to inaccurate reporting of the extracted rock mass. This relatively new for the Bulgarian reality technology is a challenge to the current legislation for monitoring the extracted volumes in the operation of quarries and mines. Apparently, new technologies could be a serious argument and catalyst in this regard.

The TLS technology adds new quantitative and qualitative dimensions to the research of the structural disturbance of rock mass. Based on an extremely detailed 3D model, even of hard-to-reach sections of rock mass, a realistic clustering of cracks is possible, creating adequate prerequisites for determining the area cracking coefficient of the rock mass. Moreover, terrestrial laser scanning data are an indisputable source of information on rock surface roughness.

As a kind of summary of what has been said, it could be stated that the 3D laser scanning technology creates new opportunities for a complex, detailed study of the structural disturbance of rock mass which are unattainable by conventional methods. The preconditions created by the competent application of laser technology open up opportunities for researchers for larger and more in-depth studies.

References
[1] Shtereva, K., Monitoring during operation of open pit mines by ground laser scanning, dissertation, 2018. (in Bulgarian)
[2] Stereva, K., Postolovski, A., Gospodinov, S., Sobieski, A., Monitoring of the extraction in stone-
pits by Terrestrial Laser Scanning. 13th International Multidisciplinary Scientific GeoConference SGEM 2013, Albena, Bulgaria, 2013

[3] Gospodinov, S., Vulkanov, N., Shtereva, K., Ground laser scanning - a new reality in the exploitation of stone quarries. Fourth National Scientific and Technical Conference with International Participation, Devin, Bulgaria, 2014. (in Bulgarian)

[4] Koprev, I., Technology of extraction of rock facing materials. (in Bulgarian)

[5] Tsvetkov V.Y., Titov E.K., Spatial modeling for mobile laser scanning. Methods and Software for Information Service in Information and Spatial Fields, pp. 31-39, 2020. (in Bulgarian)

[6] Gospodinov S., Three-dimensional information situation. European Journal of Technology and Design, T. 14. № 4. С. 152-158, 2016.

[7] Shaytura S.V., Gospodinov S.G., Vaskina M.Y.,, Complex digital model of area monitoring. Methods and Software for Information Service in Information and Spatial Fields, pp. 51-57, 2020. (in Bulgarian)

[8] Abell´an, A., Jaboyedoff, M., Oppikofer, T., Vilaplana, J., M., Detection of millimetric deformation using a terrestrial laser scanner experiment and application to a rockfall event. Natural Hazards & Earth System Sciences, 9, 365–372, 2009.

[9] Oppikofer, T., H.S.S. Bunkholt, H.S.S., L. Fischer, L., Saintot, A., Hermanns, R.L., Carrea, D., Longchamp, C., Derron, M., Michoud, C. & Jaboyedoff, M., Investigation and monitoring of rock slope instabilities in Norway by terrestrial laser scanning. Landslides and Engineered Slopes: Protecting Society through Improved Understanding – Eberhardt et al. (eds), 1235-1241, 2012.

[10] Pernito, M., Pernito, M., /2008/ Rock mass Slope Stability Analysis based on 3D TLS and Ground Penetrating. ITC, 112 p., 2008.

[11] Bauer, A., Paar, G., Kaufmann, V., Terrestrial laser scanning for rock glacier monitoring. International Conference on Permafrost, Zürich, Switzerland, 55-60, 2003.