Study of the rock masses' fracture through OPTV (Borehole Digital Optical Televiewer)

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ABSTRACT: The article describes an innovative survey methodology through the use of a digital borehole camera OBI40-2G, from which it is possible to analyse the 360° colour image of the borehole walls. It is then possible to obtain, from the virtual core, the discontinuity characteristics, the geological changes and the lithological variety. This article analyses in depth the technologies utilized for the abovementioned surveys, the proof methodologies, the data elaboration and interpretation phases, as well as the possible implication of the collected data. This survey methodology allows us to have useful information for the 3D representation of the lithological and geological model, as well as to have the possibility to use the obtained fracturing information to develop numerical models to the distinct elements "DEM".

Keywords: Borehole Loggin, Well Loggin; Deposit Sizing; Mineral Deposit Mining; Site Characterization

1. Introduction

The knowledge of the rock masses' fractures is highly relevant when dealing about rock mechanics and geotechnical problems. The optical survey camera OPTV (Borehole Digital Optical Televiewer) allows to record the borehole wall image at 360°, oriented with respects to the North.

The fractures can be recognized through sinusoidal curves readable on the image. From the abovementioned curve, it is then possible to deduce the inclination, immersion and openness of the discontinuities. Furthermore, from the virtual core is possible to analyze the lithological changes and the commodities varieties characterizing the site.

Having obtain the above-mentioned information, through innovative technologies allows us to create and visualize the geological models in 3D, so to make them easier to read and to understand.

The current article describes this innovative survey methodology, utilizing few examples of practical use and representation of the collected and elaborated data.

The azimuthal resolution is of 1800 pixel, while the vertical one, on the basis of the proof speed, can reach 1 mm [1].

The scope is inserted in the survey hole through a winch, equipped with a recording cable which enables the flow of information between the scope and the datalogger.

The acquisition system allows the visualization and the printing of the data in real time. Moreover, the control

2. Equipment and proof phase

An optical camera has been used to perform the surveys, namely the *OBI40-2G* produced by the *Mount Sopris Instruments*. This kind of instrument is equipped with an optical sensor CMOS able to perform highly resolutions combined with a fisheye objective. The instrument is thus able to produce a digital 360° image of the borehole, both with water than without. The scope is also equipped with a orientating system highly accurate, which includes a 3 axes magnetometer and a 3 axes accelerometer which enables the orientating system of the images at a global reference, as well as the determination of the azimuth and of the hole inclination. The obtained image from the OPTV can integrate or even replace the survey performed through coring system, solving the related problems of rescue and orientation of the surveys.

The scope illustrated in the Fig. 1 has a diameter of 40 mm, and it can be utilized to investigate borehole from 76 mm to 176 mm. It is also equipped with a LED light source able to enlighten the wall of the hole.

unit is in communication with a notebook through a USB interface, which permit the recording and the memorization of the data transmitted from the scope.

The boreholes can be carried out both core drilling than downhole drilling. Furthermore, the scope is consistent with the common covering systems used to reinforce the wall of the borehole. It can be investigated both horizontal, inclined and vertical holes, through pushing pole.

Figure 1. Optical scope OBI40-2G.

Generally speaking, both percussive and rotative drilling methods can be utilized. When percussive drilling methods are performed, in order to have an easier reading of the hole the survey should be cleaned with pressured water and air.

The acquisition can be performed both during the descendent phase than in the retrieval phase. Le proof speed is about 1,5m/min and it gives an image of the borehole wall then used for the data processing phase.

3. Data elaboration phase

The data acquisition and interpretation are being done through the *WellCAD* [2] software, supplied by *ALT Software* thanks to which, as shown in Fig. 2, is possible to change the log, to analyze and present the data collected from the surveys. The discontinuities can be selected manually or automatically recording dipdir, dip and openness [3].

For the data elaboration phase is extremely important to know the correct orientation of the survey hole to map it consistently to the space.

The acquisition control unit can provide two fundamental valor: the first angle represents the inclination of the drilling axes with regard to the zenith and it can go from 0° to 180° depending if it is vertical to the high or to the low.

The second angle represents the azimuth axe of the hole measured with respect to the North and it can assume values from 0° to 360°, depending on how it is distant from the North clockwise.

These values can be summarized in a graph on the function of the hole depth, so that its trend in the space can be visualized, in case the survey would not result perfectly straight.

Having reached this point, the geological structures can be classified on the typology (broken zone, fracture, joint, foliation, banding) adding features (permeable, mineralized, altered, intersected, ecc).

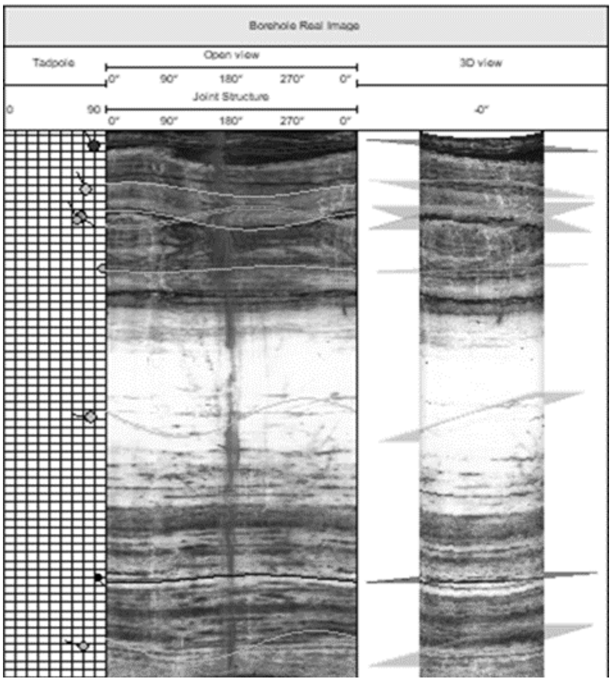
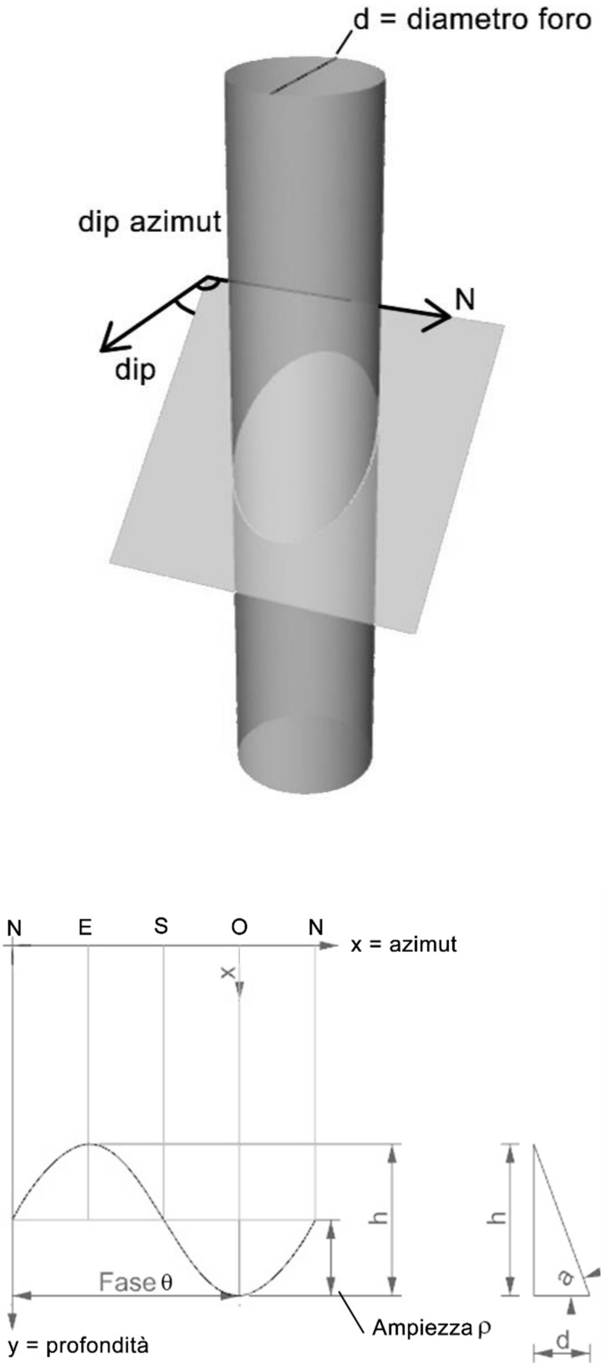


Figure 2. Discontinuities section example with WellCAD.

The fractures plans are visualized as sinusoidal curves in the 2D developed image captured by the OPTV. As shown in Fig. 3, their orientation and immersion can be obtained from the study of the aforementioned curves, mathematically descripted from the sine, correlating the phase and the openness of the associated sinusoidal.



$$y = \text{prof} + \rho \sin (x - \theta) \qquad \text{eq. 1}$$

$$\text{tg}\,\alpha = h/d \qquad \text{eq. 2}$$

Figure 3. Relationship between the intersected plan with the OPTV in the survey hole and its 2D development, with the correlated values of immersion and orientation.

Having collected the structures' characteristics intercepted by the drills, a frequency analysis of the orientation and immersion values can be performed, through a rosette diagram (circular frequency histogram) or through stereographic projection (equal frequency curves circular diagram) and analyze the typology through frequency histogram.

The collected data are then useful to determine the most diffused classifying criterion of the rock masses, namely the RMR (*Rock Mass Rating, Bieniawski*, 1976), the GSI (*Geological Strength Index*, Hoek, 1995) and the Q value (*Quality Index*, Barton, 1974).

In addition, the recovery percentage of the coring is easily evaluable, translated by the RQD parameter (*Rock Quality Designation*, Deere, 1963).

4. Creation of a geological – merceological 3D model

The images interpretation can then provide information about several geological elements (lithological contacts, commodities quality, alterations, etc.) and structural elements (fractures, faults lines, foliations, etc.)

For a quicker and more intuitive lecture of the information obtained from the OPTV and surveys in situ, a 3D geological-merceological model can be realized.

Starting from the photogrammetrical and Lidar surveys, the topographic model can be constructed. Thereafter, it is possible to perform an interpolation of the obtained data, integrating the different lithological contacts in the survey phases and the other useful information, so that their trend in the rock masses can be constructed.

The thus obtained model can give a clear 3D view of the strength of the deposit, it can be utilized to realize map and geological sections of the area, and it can evaluate the interaction of the different geological formation with eventual geotechnical actions. In this way, the obtained results can be transmitted with clarity and with an easier comprehension to clients, stakeholders and colleagues.

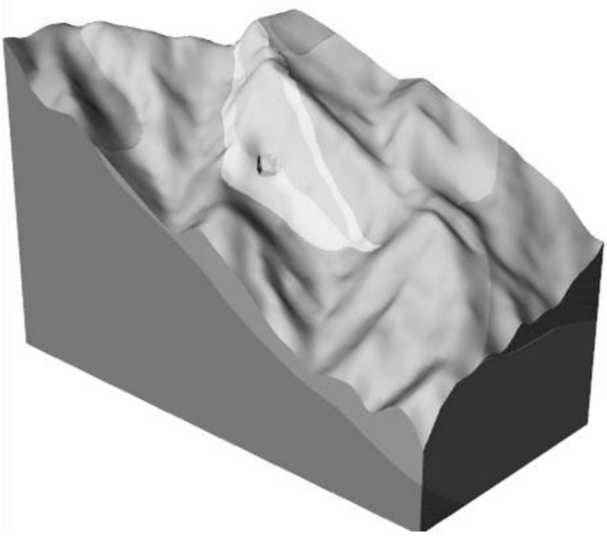


Figure 4. 3D axonometric view of a marble quarry of the Apuan Apls geological model.

In the following examples, illustrated in Fig. 4, Fig. 5 and Fig. 6, the 3D reconstruction of the geological model of a marble quarry of the Apuan Alps is being shown, developed to optimize the use of the resources.

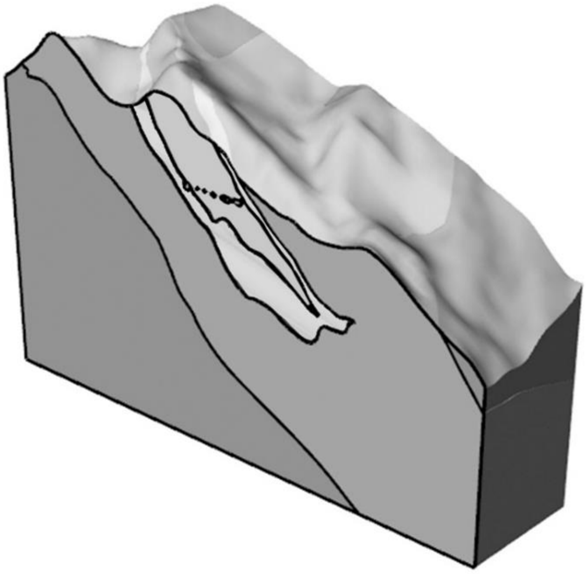


Figure 5. Longitudinal 3D sections in the geological model of a marble quarry of the Apuan Alps.

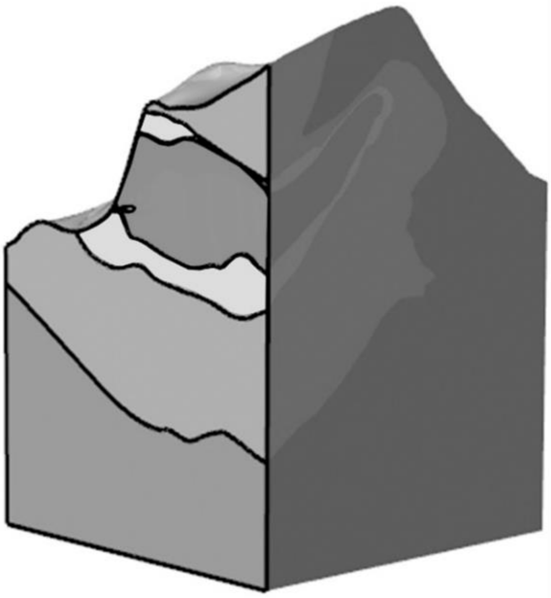


Figure 6. Transversal 3D sections in the geological model of a marble quarry of the Apuan Alps.

5. Creation of 3D distinct elements numerical model

The mapped fractures can be integrated with the most modern techniques of discrete elements numerical modelling, utilizing the dimensions, orientation and positioning values, during the model realization phase.

The distinct elements method (DEM) is a numerical solution utilized to describe the mechanic behavior of the discontinuous corps. Introduced by Peter Cundall (!971), the DEM has been developed for the analysis of the rock mechanics problems utilizing polygonal deformable blocks applicated to the ground (Cundall and Strack, 1979). This has led to the development of software such as *UDEC* (Universal Distinct Element Code) and *3DEC* (Three-Dimensional Distinct Element Code) supplied by *Itasca*. Another useful software produced by Itasca is *PFC* [4], which is a simplified implementation of DEM since it uses hard disks (*PFC2D*) or spherical particles (*PFC3D*) to significantly simplify the contact between the elements, in order to obtain model solution faster.

The fractures or joints obtained from such surveys can be modelled deterministically, representing it in the model, specifying a crossing point, the immersion direction and the inclination.

The alternative is the stochastic representation of the fractures. Through this approach, the fractures are not modelled explicitly, but they are generated on the basis of random input.

5.1. Description of the fractures with DFN (Discrete Fracture Network)

In this representation typology, the fractures are approximated to disk shaped surface. In order to generate a DFN model, the following values have to be provided:

- *Density:* the Pij notation is utilized. It has been introduced by Dershowitz et al. (1998) [5] to distinguish the several parameters of joint density through the interpretation of the surveys performed by OPTV, representing the total number of the fractures per unity of volume P_{30} $[L^{-3}]$, area P_{20} $[L^{-2}]$, lenght P_{10} $[L^{-1}]$.
- *Dimensional Distribution:* the dimensional distribution of the fractures is being defined by a probability function which describes the distribution of the diameters of the disks.
- *Position:* he fractures' position is being defined by a probability functions which describes a vector in the space.
- *Orientation:* the orientation is defined by the immersion angle and by the inclination.

In the following example, it is shown as it is possible to calibrate a DFN model starting from the fracture's intensity detected 1D in the borehole, in order to obtain a 3D model prediction.

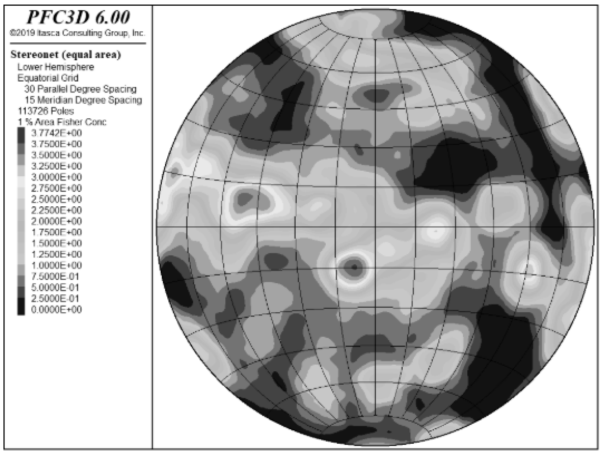


Figure 7. Stereographic projection with tree set of fractures.

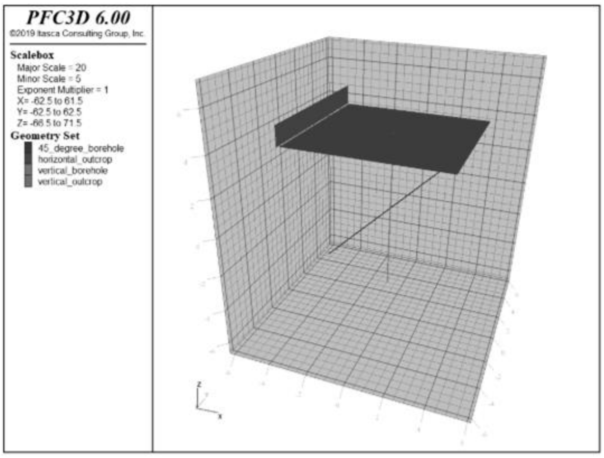


Figure 8. Borehole position (one vertical and one 45 ° inclined) used for the DFN model generation.

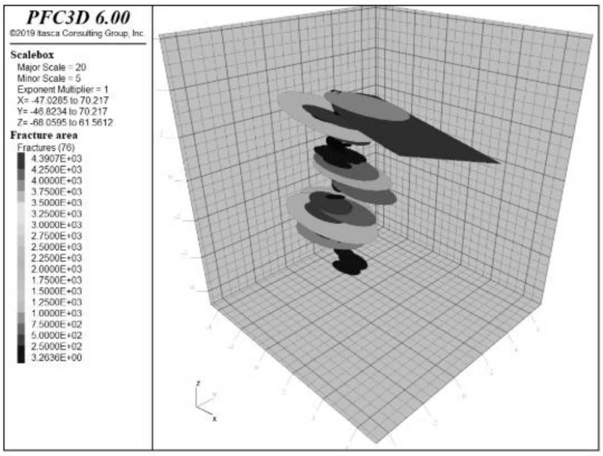


Figure 9. Fractures that intersect in vertical borehole.

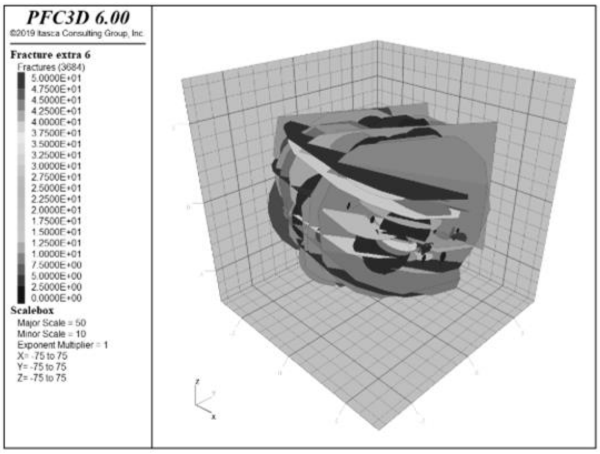


Figure 10. Simplified DFN model calibrated on the fracturing values in the 1D observation.

The DFN model has been defined by a classical description of the fractures (that is to say, different fractures families whose densities are defined by the apparent intensity of the fracture along the hole and the scansions lines, by the mass density or by the fractures number) utilizing the four parameters abovementioned.

6. Conclusions

The survey methodology described in the article has been successfully applied by Pandolfi Engineering Staff in a number of Italian, Greek and Portuguese stone material quarries.

The optical scope OBI20-2G has allowed to investigate both vertical and horizontal boreholes. From the virtual core obtained, discontinuities characteristics, lithological changes and geological varieties has been deducted. This information has been useful to complete the classification of the rock masses and to then evaluate the fracture degree.

The geological and merceological model has been performed the 3D reconstruction of the geological and merceological model, and the fractures revelated has been utilized for specific numerical analysis to the Distinct Elements.

The abovementioned 3D virtual model elaborated by Pandolfi Engineering has been names as *Materia*® (3D model with geological and merceological information), *Structura*® (3D geo-structural model of the rock masses) and *Mathematica*® (numerical model FDM "Finite Difference Method" or DEM "Distinct Element Method" of the quarry).

7. References

[1] Mont Sopris Instrument Co. Inc. (2015). Release note_OBI40-2G. www.montsopris.com, Denver 5p.

[2] ALT Advanced Logic Technology (2017). WellCAD, The Universal Borehole Data Toolbox. www.alt.lu, Luxembourg 28 p.

[3] Li S. J., Feng X.T., Wang C.Y., Hudson J.A. (2012). ISRM Suggested Method for Rock Fractures Observation Using a Borehole Digital Optical Televiewer. The ISRM Methods for Rock Characterization, Testing and Monitoring: 2007-2014. R. Ulusay (ed), 159-168.

[4] Itasca (2019). PFC 6.0 documentation. www.itascacg.com/software/pfc

[5] Dershowitz W.S., Lee G., Geier J., Foxford T., LaPointe P., Thomas A. (1998). FracMan interactive discrete feature data analysis, geometric modelling, and exploration simulation. User documentation. Version 2.6, Golder Associates Inc., Seattle.