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Geo-Mechanical Characterization of Carbonate Rock Masses by Means of Laser Scanner Technique

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Abstract. Knowledge of the geometrical and structural setting of rock masses is crucial to evaluate the stability and to design the most suitable stabilization works. In this work we use the Terrestrial Laser Scanning (TLS) at the site of the Grave of the Castellana Caves, a famous show cave in southern Italy. The Grave is the natural access to the cave system, produced by collapse of the vault, due to upward progression of instabilities in the carbonate rock masses. It is about 55-m high, bell-shaped, with maximum width of 120 m. Aim of the work is the characterization of carbonate rock masses from the structural and geo-mechanical standpoints through the use of innovative survey techniques. TLS survey provides a product consisting of millions of geo-referenced points, to be managed in space, to become a suitable database for the morphological and geological-structural analysis. Studying by means of TLS a rock face, partly inaccessible or located in very complex environments, allows to investigate slopes in their overall areal extent, thus offering advantages both as regards safety of the workers and time needed for the survey. In addition to TLS, the traditional approach was also followed by performing scanlines surveys along the rims of the Grave, following the ISRM recommendations for characterization of discontinuity in rock masses. A quantitative comparison among the data obtained by TLS technique and those deriving from the classical geo-mechanical survey is eventually presented, to discuss potentiality of drawbacks of the different techniques used for surveying the rock masses.

1. Introduction

Knowledge of the geometrical and structural setting of rock masses is crucial to evaluate the stability and to design the most suitable stabilization works. The traditional survey techniques are often expensive, and present great difficulties related to logistics in accessing the sites, to the high hazards for the operators, and to the height of the rock faces, or simply because of the wide extent of the rock walls to be examined. To solve such problems, and with the aim to characterize rock masses from both the structural and geo-mechanical standpoints, in recent years' innovative survey techniques including the use of the Terrestrial Laser Scanning (TLS) have been introduced.

TLS survey provides a product consisting of millions of geo-referenced points, to be managed in space, to become a suitable database for the morphological and geological-structural analysis. Studying by means of TLS a rock face, partly inaccessible or located in very complex environments, allows to investigate slopes in their overall areal extent, thus offering advantages both as regards safety of the workers and time needed for the survey.

In this work we present the results of a study carried out in one of the most famous karst sites of southern Italy, the Castellana Caves. This remarkable karst system, discovered in the 1930s by Franco Anelli [1, 2], at that time Director of the Italian Institute of Speleology, soon became show cave [3], and since then it represents karst and its wonders to thousands of visitors. The most spectacular view of the system is without any doubt the *Grave*, a natural opening created by sinkhole processes, with repeated falls from the vault, which upward progression led eventually to open a 55-mt deep window to the cave below. The name *Grave* is locally used to designate deep access to underground cave system, and derives from the pre-Latin term *grava*, which means pit or hole, and from the messapian term *graba*, meaning erosion of a river bank [4]. This type of feature, produced through sinkhole collapse [5, 6] is very common in the karst of Apulia [7, 8, 9]. Local bedrock is represented by stratified Cretaceous limestones [10], belonging to the palaeo-geographic domain of the Apulian Carbonate Platform [11, 12], which acted as foreland during the building-up of the Southern Apenninic Chain.

Main features of laser VZ 400:

- Class 1 Laser
- Distance > 500 mt
- Metric photocamera with optical features calibrated at high definition (>6 Mpixel)
- First and last impulses
- Ability to reduce the shadow areas due to vegetation
- Integrated inclinometric sensor
- Integrated GPS antenna
- High acquisition speed: min. 122.000 pts/sec
- Scan angles: 360° horizontal – 360° vertical
- Precision: ≤ 5mm
- Integrated compass

Figure 1. Laser scanner RIEGL VZ400 and its main features

2. 3D laser scanner survey at the Grave of Castellana Caves

The site of the Castellana Caves, located in the municipality of Castellana-Grotte (Apulia, southern Italy), has already been object of studies dedicated to structural analyses and evaluation of the characters of the local rock mass, with particular relation to instability [13, 14]. In the occasion of the present work, the *Grave* has been analysed through a survey carried out by means of the laser scanner RIEGL VZ400 (figure 1). Laser scanner techniques have been recognized since several years as a powerful tool of investigation for rock masses [15, 16, 17], especially when these present difficult logistic conditions.

During the survey, a geo-referenced point cloud of 430.000 million of points was obtained (figure 2); each of the point is characterized by the related geographic information (X,Y, Z), as well as by the chromatic one (RGB) and by the characters of reflectivity (i). The survey consisted of 42 scans, general and detailed as well, for a total of 20 scan-positions, with 8 of these located outside the *Grave*, and 12 within. For each survey station, several scans have been performed, with different resolutions. The data acquired in the field have been processed by means of dedicated software. The elaboration process consisted, first, in linking and roto-translating the different point clouds acquired. Such operation is of primary importance, and requires the use of targets with high reflectivity, geo-referenced by GPS and high-precision topographic total station. Then, the point cloud was optimized by cleaning the dataset. In this way, from the original point cloud a solid surface (mesh) was obtained, which is able to represent the geometry of the *Grave* at high detail (figure 3).

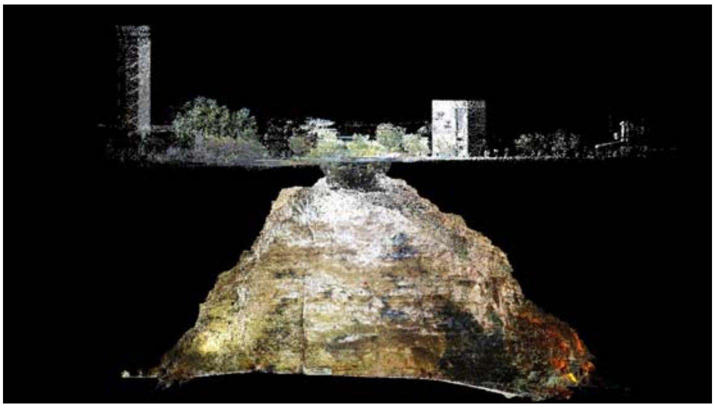

Figure 2. Point cloud – Real numerical model

Figure 3. Inner view of the Grave – Texturized surface

3. Surveying

3.1. Geological-structural analysis

The geological-structural analysis of the *Grave* was performed through innovative methodologies which considered the measure of the discontinuities directly in the point cloud. Specific software allowed to analyse the attributes of the point cloud, and, more precisely, the values of the normals associated to each point. These, defined as the vector perpendicular to the plane tangent at that point, are described by three spatial coordinates.

The procedure initially consisted in analysis of the normals, with the aim to identify those sectors showing similar orientation. These values have been later characterized by assigning to the point cloud a new attribute, computed by associating the attitude (Dip/Dip Direction) to the value of the normal at each point. Eventually, all the points showing similar attitudes, within a pre-defined variability range, have been grouped along the geological lineation's of interest, to better interpolate the planes which adapt in the best way to the identified point distribution. This is a semi-automatic method, with manual control and validation, since the computational phase of identification, computation and conversion of the normals in geological datum, is proceeded by a process of manual selection of the elements to be modelled, guided by experience of the operator, who is in this way able to fully control the output.

The planes so identified, described by the average parameters of dip and dip direction, have been portrayed in stereographic projections (figure 4), by ranking the data in families of discontinuities. Since most of the attitudes show high dip, the possible variation in polarity of the discontinuity, related to a likely undulated plane, has been taken into account. One hundred and thirteen discontinuity measurements have been taken along the walls, and at least three main families of discontinuities have been identified, in addition to the bedding, as summarized in Table 1.

Table 1. Average attitude of the main families of discontinuity, identified through geological-structural analysis on point cloud.

family	*dip direction*	*dip*
K1	52	87
K2	151	85
K3	185	85
S'	212	4
S''	35	3

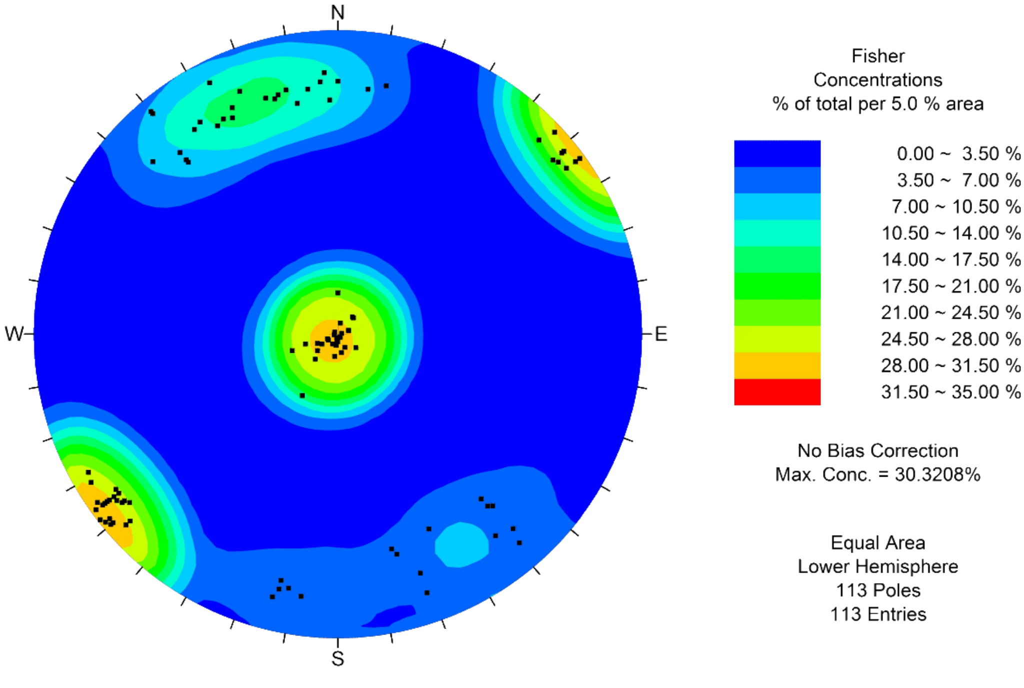

Figure 4. Vault of the Grave – Density chart of the poles of main discontinuities, identified through geological-structural analysis on point cloud

3.2. Geological-structural analysis and geo-mechanical surveys

Two scanlines have been performed along the walls of the *Grave* through traditional survey, thanks to the availability of geologist-climbers. Along the scanlines, following the recommendations suggested by the International Society for Rock Mechanics [18], the progressive location, orientation, spacing, aperture, filling materials, persistence and roughness, have been measured for each discontinuity crossing the scanline, aimed at identifying the families of discontinuity in the rock mass, and to estimate their mechanical properties.

The data so acquired (no. 46) have been collected and represented in polar equiareal projection, and have been analysed through a cluster analysis. The field data allowed to identify, besides the bedding, three main families of discontinuity (Table 2); in addition to these, some random discontinuities were also measured.

3.3. Quantitative comparison among different techniques

Eventually, a quantitative comparison among the different techniques used for surveying the rock masses ("classical" geo-mechanical survey, and digital survey from cloud point acquired by TLS) was carried out. Comparing the two datasets, it appears that a good agreement is reached between the data obtained by the different techniques. This follows the outcomes from previous studies, where the same techniques have been successfully used and compared [19]. The slight differences observed should be attributed to the logistic difficulties in performing survey along vertical or overhanging rock walls.

Table 2. Average attitude of the main discontinuity families identified by means of the classical geo-mechanical survey in rock walls.

Measure station	*Discontinuity family*	*Dip direction*	*Dip*
ST1	S'	322	6
	S'	208	8
	K1	237	84
	K2	298	83
	K3	24	87
ST2	S'	354	4
	K1	225	88
	K2	319	88
	K5	51	46

4. Conclusions

Analysis of carbonate rock masses is complicated by the presence of karst features, which are typically not considered in the classical geo-mechanic's approaches [20, 21]. Complexity of karst make this environment particularly difficult to be examined, and in many cases engineering works have to be carried out very carefully, only after a thorough knowledge of the karst features have been reached [22], in order to reduce the likely negative consequences of wrong decisions and works [23]. At this goal, we have presented in this paper the use of TLS survey, which may be precious, allowing to obtain, as shown in this study, highly precise data in logistically difficult conditions, thus providing practitioners with the necessary amount of data to design and realize the specific projects.

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