Innovative Application of "Giraffe" Technique For Dam Foundation Mapping

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Introduction

The geotechnical assessment of a dam foundation is of primary importance in the design process and during the construction phase; it is a prerequisite of the foundation treatment and supports the post-construction monitoring.
Once the designed foundation surface has been reached, the preliminary characterization based on field investigations must be refined by means of detailed mapping activities, usually carried out by delimiting small areas to be surveyed and manually sketching and measuring the observed geological and geo-structural features.
An innovative technique has recently been tested during the excavation of foundation of the Grand Ethiopian Renaissance dam project (GERdp), in Ethiopia. This plant includes a main Roller Compacted Concrete (RCC) dam about 1800 m long and 150 m high and a rockfill saddle dam about 5000 m long and 50 m high with a foundation area of about 185.000 m^2 and 640.000 m^2 respectively. It is easy to imagine the hard task of mapping such a large surfaces adopting conventional methodology.
In order to speed up the foundation mapping and to improve the accuracy of the information acquired, large areas of the foundation were photographed using a camera attached to a telescopic pole, so-called "Giraffe".
The camera, remotely controlled using a tablet with a Wi-Fi connection, took pictures of the foundation plan from a maximum height of 10 m, assuring the proper framing and overlap necessary for the photogrammetry processing.
In order to improve the accuracy of the results of the georeferencing process, a number of ground control points marked on the foundation surface had to be topographically surveyed.
The pictures were then processed by photogrammetric technique, obtaining a georeferenced three-dimensional model of the foundation surface that contains all the information on the topography, main lithological limits and geo-structural features (i.e., length and direction of the discontinuities).
This procedure is faster and more accurate that a traditional geological/geotechnical survey and has the added advantage of having georeferenced images and a Digital Terrain Model (DTM) that allow the survey to be documented for future reference/verification and also to carry out specific measurements on the digital model itself.
The speed of execution and the possibility of making observations and measurements on the digital model, as well as directly on site, makes this method particularly suitable for large areas and situations in which the foundations are being poured very shortly after mapping.

1. Background

1.1 Main Features of the Project

The Great Ethiopian Renaissance Dam Project, GERD Project, is located on the Blue Nile river, in Ethiopia, a few kilometers upstream of Roseires Dam, in Sudan (Fig.1). The reservoir will have a total capacity of about 75 billion cubic meters and will be created by means of the construction of two dams: the Main Dam and the Saddle Dam (Fig. 2). The power plant will have about 6'000 MW of installed power. The Main Dam is founded on rock and the Saddle Dam is founded mainly on residual soils.
The Main Dam is a Roller Compacted Concrete (RCC) dam about 1800 m long and 150 m high, while the Saddle dam is a Concrete Face Rockfill dam (CFRd) about 5000 m long and up to 70 m high with a foundation area of about 185.000 m^2 and 640.000 m^2, respectively.
The foundation of the Main Dam is mainly characterized by gneiss associated with amphibolite lenses. The foundation is cut in places by metric basalt dikes, while the central area of the dam foundation is affected by a marble belt.
The Saddle Dam foundation is mainly founded on residual soils for a length of about 3.6 km, and for the remaining portion on rock. The residual soils derive from different source rocks (meta-gabbro, flysch, granite), while the left and right banks are made of sericite schists and meta-granite rocky foundation, respectively.

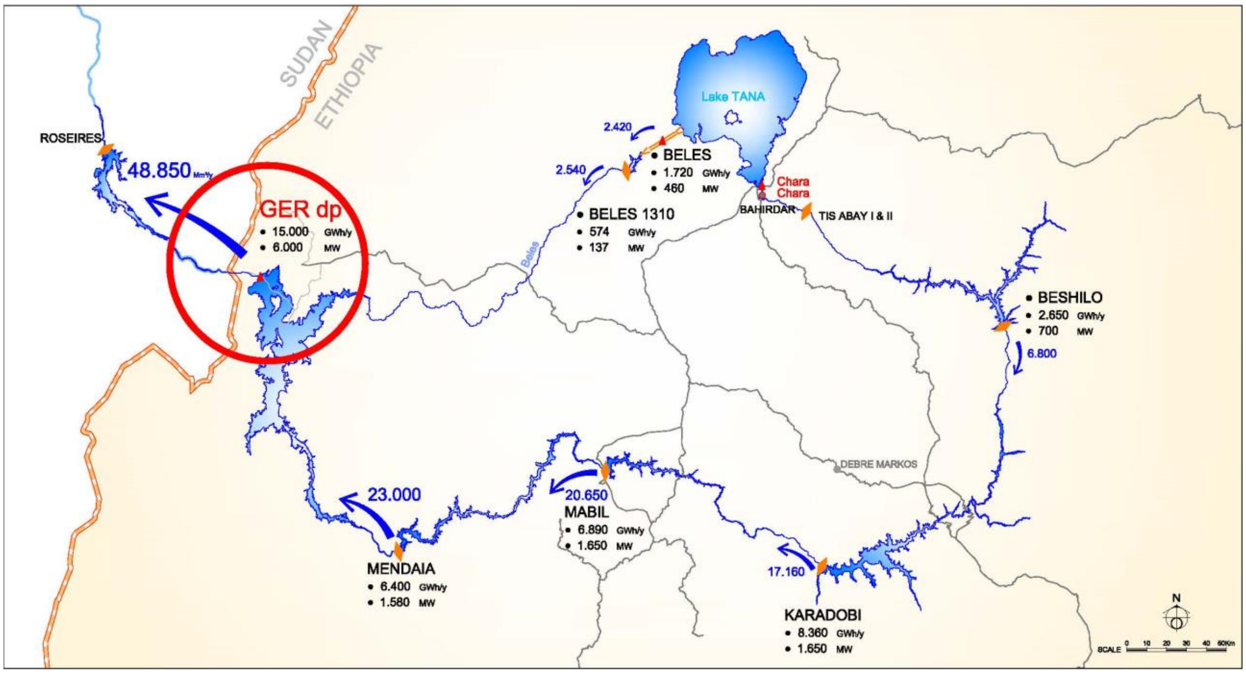

Fig. 1. Map showing the location of the GERd project along the Blue Nile river, Ethiopia..

Fig. 2. a) RCC Main dam and b) CFRD Saddle dam views.

1.2 Dam Foundation Definition and Treatment

The geological and geotechnical assessment of the dam foundations are critical issues during the design process and they are usually defined during the investigation phases. The overall information gathered from the planned boreholes (RQD,CR, lithology, etc.) and from the in-situ tests (deformability tests, down-holes tests, etc.) together with the laboratory tests (UCS, triaxial tests, sonic velocity tests, etc.) are interpreted and processed in order to characterize the dam foundation and to allow the stability analysis of the dam, subsequently.

Once the design foundation level is reached, the following steps have to be followed prior to proceeding with the concrete works:

- cleaning and removal of loose material;
- topographical verification;
- geological and geo-structural mapping ;
- rock mass classification according to the qualitative GSI (Geological Strength Index) system;
- acceptance of the foundation;
- instruction for the foundation treatments (i.e., additional excavation, dental treatment, etc.).

Geological and geo-structural mapping traditionally included characterization of the discontinuities such as orientation, roughness, aperture and infilling characteristics, if any.

To ensure an adequate foundation, the foundation geology is inspected and formally approved by the designers, geologists, and construction engineers.

In particular, the geological mapping is required to document the surface at foundation grade, by requiring the use of gridding the foundation grade and measuring and recording the geologic features within the grid, including a lithological description.

For example, in our case, the whole Main Dam foundation footprint was divided into a number of geometrically defined areas (i.e., squares of 20 by 20 meters) being part of a georeferenced grid identified by rows and columns.
Hence, each square was defined by four corners whose absolute coordinates were usually mapped by the contractor surveyors. Once the given area was cleaned the traditional foundation mapping methodology consisted of:

- fixing six roller metric tapes (four at each side and two at the diagonals);
- mapping each geological feature (fault, joint, lithological boundary) by measuring its intersection with the metric tapes;
- drawing the geological features on a paper where the relevant scaled grid square was printed;
- assigning a rock mass classification through the GSI qualitative method;
- acceptance of the foundation.

A similar procedure was used for the foundation of Saddle Dam concrete structures among which:

- upstream inspection gallery;
- drainage gallery;
- access galleries.

Fig.3 outlines the traditional methodology used to map a foundation grid particle at GER Main Dam prior to applying the photogrammetric approach. As highlighted, the cleaned foundation is usually defined by placing metric tapes.

Fig. 3. Traditional foundation mapping setting.

However, traditional rock foundation mapping, especially in large projects, necessitates many man-hours on site by geologists and engineers to georeference the foundation features, manually record geotechnical data, and then many hours in the office to assemble them into a meaningful format. The conventional method is a proven method, but time-consuming and labour intensive. Furthermore, the final foundation acceptance map is lacking as to what the foundation materials actually look like visually, just prior to construction.
Recent technological improvements in both digital cameras and photogrammetric processing software have resulted in another tool at the disposal of the engineering geologist for use in geologic mapping. The purpose of this paper is to illustrate how photogrammetry has been successfully used to enhance the level of geologic mapping for foundation acceptance and to provide concise archival documentation.

2. "Giraffe" Methodology

2.1 Introduction

Mining and tunnelling industries have replaced traditional mapping methods and relied on 3-D photogrammetry to characterize and analyse geotechnical and structural information for their applications. As known, photogrammetric mapping has also the advantage of mapping discontinuities of a surface without having to access the face [1]. In mining, this would minimize exposure to dangerous slopes, because the mapping can be done from georeferenced photos, without having to physically be close to the potentially unstable rock face. The photogrammetric mapping method in tunnels or shafts allows quick assessment of the potential failure modes by rapid collection and processing of geotechnical data.
In this work close-range photogrammetry technology has been applied to the dam foundation mapping.

2.2 Methodology

The geological mapping procedure was performed following the conventional steps with the addition of a digital close-range photogrammetric approach which has been introduced to speed up and to improve the quality of the collected data.
Therefore, once the foundation level has been reached in a given area the geologists has to proceed with the following steps:

1. definition of the area to be mapped and approved;
2. evaluation of the state of cleaning and instructions for additional cleaning, if necessary;
3. marking of a number of well distributed target (GCP - about 10 points every 400 m^2) with the aid of removable targets or with spray paint;
4. surveying of the target points with a total station or a GPS;
5. imaging of the foundation by mean the use of the "Giraffe" methodology;
6. processing of the photogrammetric model;
7. exporting and printing of the ortho-image;
8. on-site geological mapping by using the printed ortho-image as a base;
9. acceptance of the foundation;
10. CAD digitizing of the field mapping and documentation delivery.

In particular, collection of field digital photographs was carried out by using a compact 16-megapixels digital camera (Panasonic DMC-FT5) mounted on a 10-meter long survey staff called a "giraffe" and a wireless shutter trigger system.

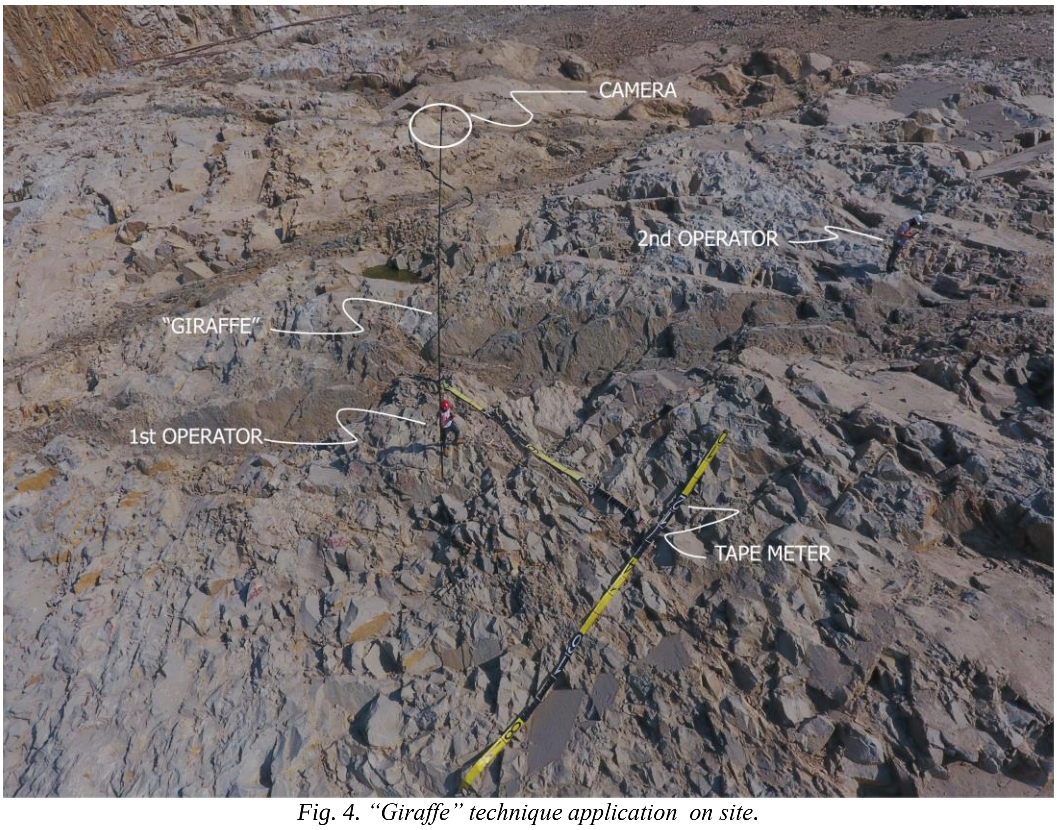

Fig. 4. "Giraffe" technique application on site.

The first operator managed the “giraffe” by regularly moving on the cleaned foundation while the second operator took pictures by means of a wireless-connected tablet. The pictures were taken according to conventional photogrammetric rules, that means that were imaged with a consistent overlapping area.
The stabilization system of the camera guaranteed high quality images while the “giraffe” was oscillating.
It has to be noted that, ideally, the whole foundation could have been mapped in short order with aerial photogrammetry if all the acceptance sections had been cleaned and exposed at one time. In reality, the contractor was working on treatment excavations in one area while excavating to grade in another area which meant mapping small areas one at a time. Actually, as the contractor usually worked down the section with the cleaning process, the geologist had to work on the portion of the same section that was already cleaned to begin the identification and marking of the features within a given section [2].
Once all the foundation had been completely photographed, accepted and mapped, the photogrammetric images and geology mapped on the field photos were collected for office work.

2.3 Results

Office work consisted in processing the pictures together with the surveyed target points by means of available photogrammetric commercial software in order to obtain the following data and results for each relevant foundation area (Fig.5):

- a georeferenced 3D-model (i.e., Fig.6);
- a DTM (Digital Terrain Model);
- contour lines;
- ortho-image.

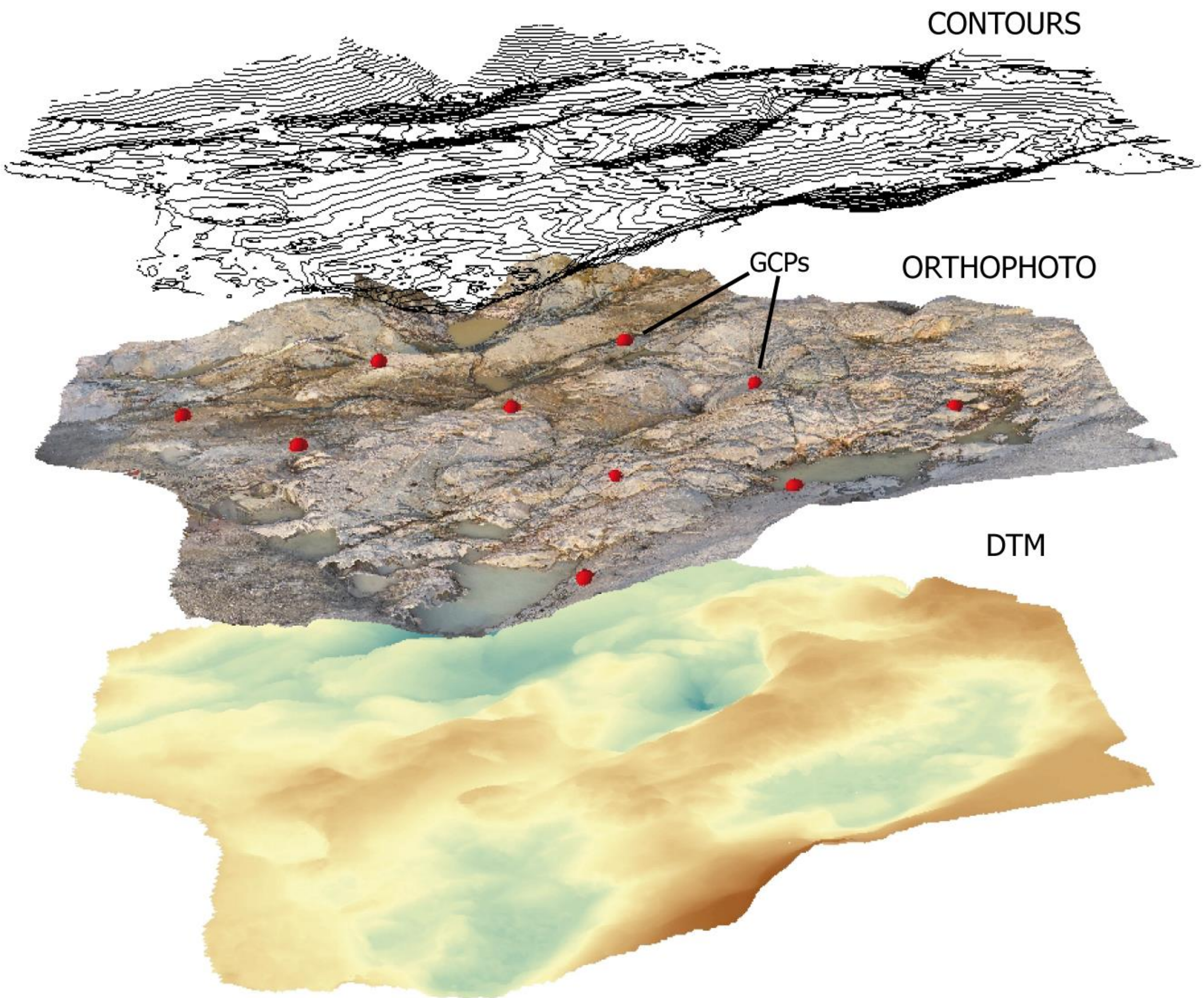

Fig. 5. 3-D outputs resulted from photogrammetric process of the images taken on site.

Fig.6. 3-D model of a typical foundation area mapped before concreting works.

The photogrammetric process outputs were subsequently used to produce a standard layout to be delivered as official documentation by drawing all the data in a GIS or CAD environment (Fig.7).

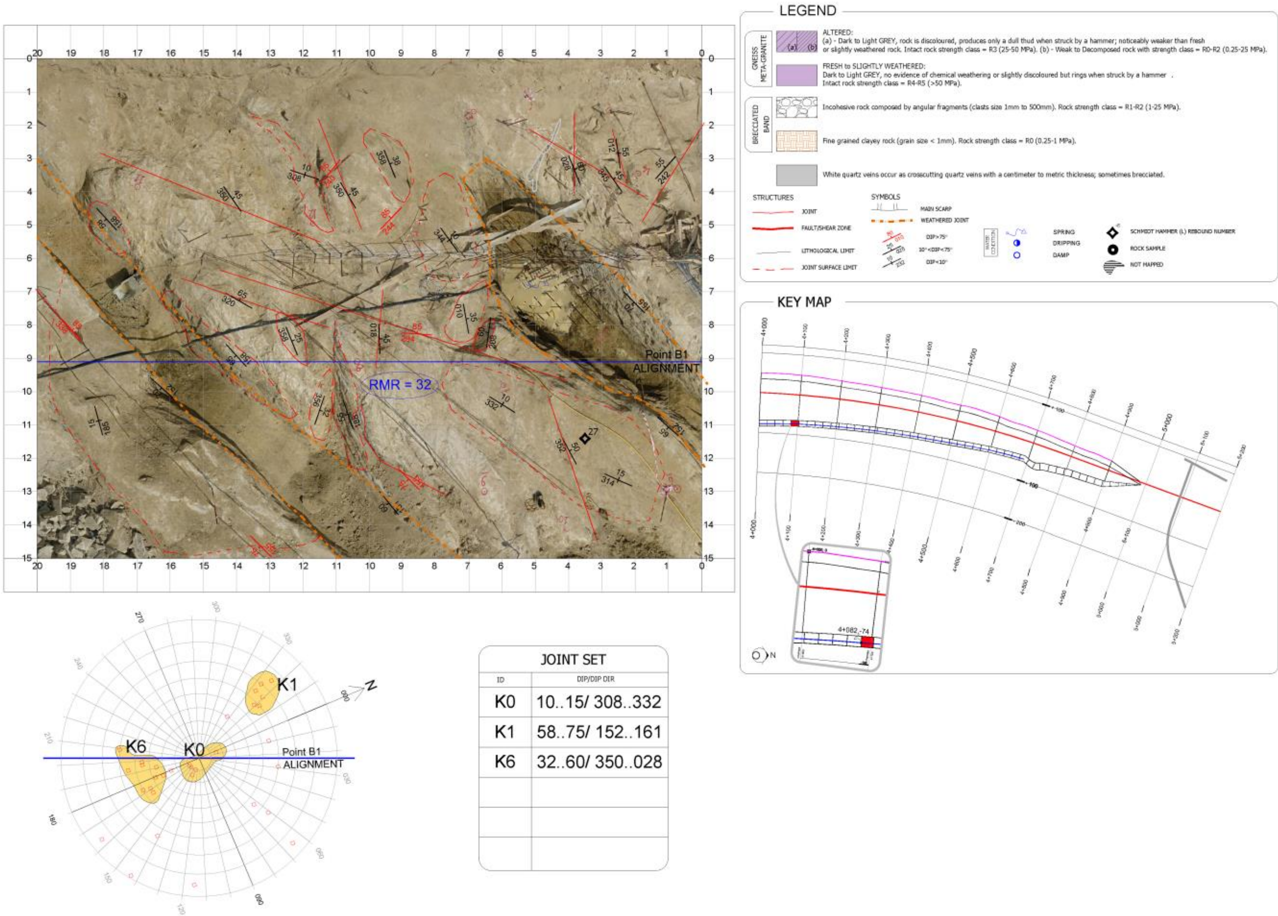

Fig.7. Example of a foundation mapping layout containing the ortho-image.

The availability of the ortho-image and the DTM surface analysis products (slope and azimuth) allowed the geologists to carried out measurements and interpretation after the concrete works had covered the foundation.

The results were then plotted into a stereoplot in order to identify the main joint sets affecting the mapped foundation stretch.

3. Conclusions and Perspectives

This work outlines a new method for geological mapping of a dam foundation. The proposed approach deals with the use of the close-range photogrammetry to speed up the conventional foundation mapping procedure by using a camera attached to a 10 m telescopic pole called a “giraffe”. The main advantages of the method are:

- rapidity in collecting field data allowing the concrete works to be executed without interferences from geological survey activities;
- improving quality and typology of the recorded data;
- storing data for further verifications and claim management.

Furthermore, due to the progress of drone technology, at the time of writing this paper the photogrammetric approach is also being applied to larger areas. In this context, photogrammetric mapping can be used for survey purposes increasing the quality and rapidity of the results together with a remarkable saving in costs.

References

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The Authors

Marco Rinaldi, geologist, obtained his Msc and PhD degree in Earth Sciences from the University of Pavia, has acquired experience in remote sensing and photogrammetry applied to structural geology and morphotectonics, besides geological data collecting and processing into GIS platform.
Since 2009, as geologist with Studio Pietrangeli he has been involved in various activities dealing with hydroelectric projects construction and monitoring, acquiring remarkable experience in the site investigation planning and supervision, in situ tests, rock mechanics and dam monitoring.

Davide D’Alberti, obtained his degree in Civil/Environmental Engineering from the University of Rome “La Sapienza”, has acquired experience in geotechnical engineering for large civil works, dams and hydropower projects in Italy and Africa.
Since 2010, as one of Studio Pietrangeli’s geotechnical specialists, he has been closely involved in all the phases of large dam projects from feasibility to final design and supervision during construction, acquiring remarkable experience in rock mechanics and grouting works.

Saverio Cutini, obtained his degree in Engineering Geology from the University of Siena. He works as geologist for Studio Pietrangeli. His multidisciplinary knowledge comprises GIS, use of drones, remote and proximal sensing and engineering geology. Over the last 5 years he has worked on several engineering and geological projects, among which Kidunda (Tanzania) and GERdp (Ethiopia) dams, which included GIS-based data management, engineering geology and topographic surveys.