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ScienceDirect

Procedia Engineering 158 (2016) 248 – 253

Procedia Engineering

www.elsevier.com/locate/procedia

VI ITALIAN CONFERENCE OF RESEARCHERS IN GEOTECHNICAL ENGINEERING – Geotechnical Engineering in Multidisciplinary Research: from Microscale to Regional Scale, CNRIG2016

Study of the mechanical properties of a conglomerate

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Abstract

This paper is devoted to the study of a conglomerate rock formation (Molare Formation) outcropping in southern Piedmont that forms a natural arch of environmental interest. Awareness with respect to the stability of this structure emerged after some intense rains which caused small collapses at the arch foot. The need for a proper characterization of the material in its natural state and its deterioration following increased water saturation is needed. A multidisciplinary approach based on the integration of both in situ and laboratory geophysical tests for the assessment of the rock structure at different scales was performed. Geological surveys together with seismic tomography and GPR have been executed on site. Petrographical and compositional studies of the matrix, ultrasonic pulse velocity measurements, electrical resistivity determinations and standard UCS test on large specimens are under development in laboratory.

Peer-review under the responsibility of the organizing and scientific committees of CNRIG2016

Keywords: REV; conglomerate; bimrocks; electrical; seismic geophyscial methods

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1. Introduction

Geomaterials with block-in-matrix texture (bimrocks), characterized by heterogeneous structures including rock blocks and clasts embedded in a fine-grained matrix (conglomerates, breccia, melanges. etc.), are a common feature in the geological record. Consequently, engineering structures are often constructed interacting with this challenging material whose mechanical response need to be properly taken into account [1].

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Peer-review under the responsibility of the organizing and scientific committees of CNRIG2016
doi:10.1016/j.proeng.2016.08.437

Unfortunately, the mechanical properties of bimrocks are very difficult to be determined by laboratory standard tests, mostly because it is problematic to obtain undisturbed core of representative dimensions [2,3]. The dimension of the embedded rock blocks makes indeed their Representative Element Volume (REV) much larger than the specimen dimension that can be tested in laboratory. Several studies are available in literature on this topic, based on laboratory tests, in situ real scale surveys and numerical modelling [3,4,5,6,7,8,9], but a clear definition of the testing procedure is not available yet. Experimental evidences agree that the failure mechanics and the resistance of bimrocks are mainly controlled by the fine-grained matrix and by its eventual alteration, particularly following rain events.

This study is carried out in Mombasiglio (Piedmont, Italy) over a so called “natural bridge” standing above the Mongia stream. This stream is a small tributary of the Tanaro River in the highest part of its hydrographic basin, in southern Piedmont (7.95 E, 44.37 N). The "natural bridge" (Fig. 1) is an outstanding geological structure, about 15 m long with an average width of 10 m. The top of the bridge stands at 9 m from the bottom stream with an arch tickness of around 5-6 m. It is therefore one of the biggest example of this kind in Europe, formed after thousand years of erosion at its basal portion. The constituting lithotype is a red polygenic conglomerate with carbonatic cement belonging to the “Formazione di Molare” (Oligocene). This conglomeratic formation is particularly difficult to be characterized due to its heterogeneity: it is not rare to find lens of coarse grey sandstones within the formation, evidence of this alternation can be indeed observed in the right abutment. The internal lithological contrasts of the formation allowed a differential erosion of the lower part of the stratigraphic sequence, preserving the more competent upper part. This was most probably related to the formation of a meander within the Mongia Stream [10] later cut allowing for the formation of the bridge.

Abundant rainfalls in the period March-April 2015 caused a landslide on the left upstream side of the bridge, at the junction with the provincial road, and formed a low consistency zone with material sinking in the river below. After this event the bridge was closed and concerns raised with respect to its overall stability. A multidisciplinary study was therefore commissioned by the Mombasiglio municipality to characterize the bridge from geological, geomorphological and geotechnical point of view. The present paper mainly describes the geotechnical photogrammetric analysis of the bridge and the geophysical investigations carried out on site in order to assess electrical resistivity and compressional wave velocity fields. Further laboratory tests (ultrasonic pulse velocity, electrical resistivity, UCS determination) are under development for a cross-validation of the results at different scales.

2. Experimental Method

2.1 Photogrammetric reconstruction

A photogrammetric survey has been performed on both sides of the natural bridge. It consisted in the acquisition of two sets of images covering as much as possible the arch surfaces, considering constraints due to the presence of water and vegetation. Since the aim of the survey was to create a total DSM (Digital Surface Model) of the visible surface of the arch in the easiest possible way and in a local reference system, we materialized a system suitable for unifying the models obtained from the two sides. Basically, we placed two level staffs so that they were visible from both sides of the arch; by means of the code Agisoft Photoscan we collimated, on both sets of images, at least 4 well recognizable points, two for each level staff. The vertical axis was made coincident with the level staff 1 and the origin was fixed at the base of it; the model was scaled by assigning a known distance, that is the length of a red part of the level staff, which is equal to 20 cm. The relative coordinates of the collimated points were properly assigned (e.g. the diameter of the level staff was taken into account), in order to make the reference system of the two sets of images coincide. By processing the two distinct sets of images (one for each side) by means of the code Agisoft Photoscan, two colored digital models were obtained. Since their reference system was identical, the operation to merge them was banal. The total model was then manually cleaned in order to delete vegetation and scattered points. The final model is composed by about 60’000 points, with a resolution of about 1 point every 10 cm. In Figure 2, a View of Side 1 of the total model, after deleting vegetation and scattered points is reported. This model has been adopted for the final rendering of geophysical results and the development of the bridge stability analysis.

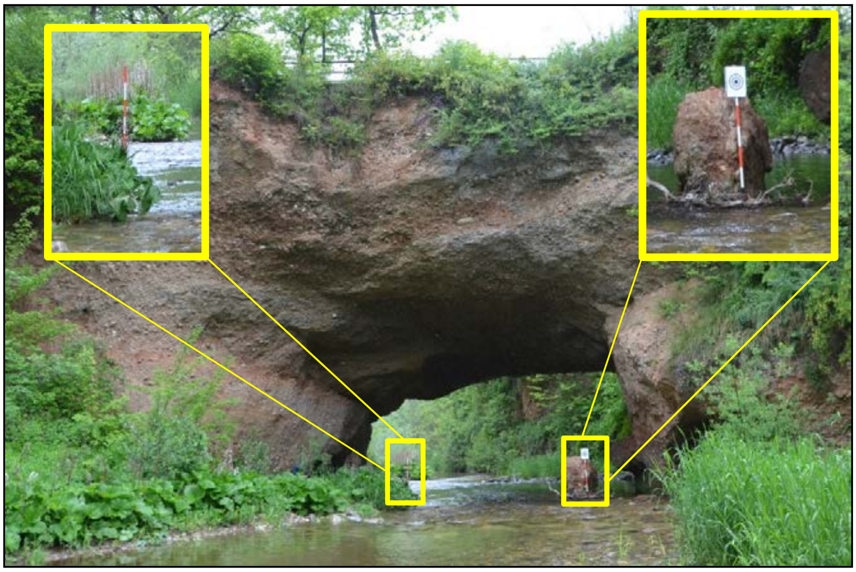

Fig. 1. View of the natural bridge with details on the two level staffs, visible from both sides, used for the construction and scaling of the global DSM.

Fig. 2. View of Side 1 of the total model, after deleting vegetation and scattered points.

2.2 *Photographic analysis*

The rock structure of the natural bridge has been investigated by a photogrammetric procedure thought the software Split Desktop. The latter is able to reproduce the grain size distribution starting from a simple picture of the deposits. Since this software was developed for rock debris analyses, it is not automatically suitable for the grain size analysis of clasts embedded in a fine matrix and required therefore considerable additional manual processing of the images. Several pictures were analyzed at different scales: from the whole bridge scale to the laboratory specimen scale.

Fig. 3. Pictures of the rocks analysed with image analysis (Detail 1 and Sample 5 in the following figure).

In a first phase, the software performs automatic delineation of the grain boundaries which, however, as mentioned earlier, is optimized for the analysis of fragments and for this working context implied a massive process of manual correction. In order to obtain reliable information, only grains identifiable by the automatic delineation (larger than a few mm for these images) have been considered and consequently, the results obtained are related only to the portions of rock greater than a few millimeters, disregarding the fine matrix grain size distribution. The obtained results are summarized in Figure 4, where it can observe that the grain size distribution of the rock is strongly dependent on the analyzed sample size and that the curves progressively shift towards right for increasing rock portions. The average grain size raises with increasing considered rock portions (from about 1 cm at the laboratory scale to 3 cm at the bridge scale). However, all the curves tend towards a stabile distribution at the dimensions of the so called Detail 1 (about 1m^3) indicating that this can be considered the Representative Element Volume of this kind of rocks. These results also indicate that the sample sizes which could be tested at the laboratory scale (e.g. through UCS determination) are statistically non-representative and nondestructive geophysical tests on larger rock portions have been consequentially preferred.

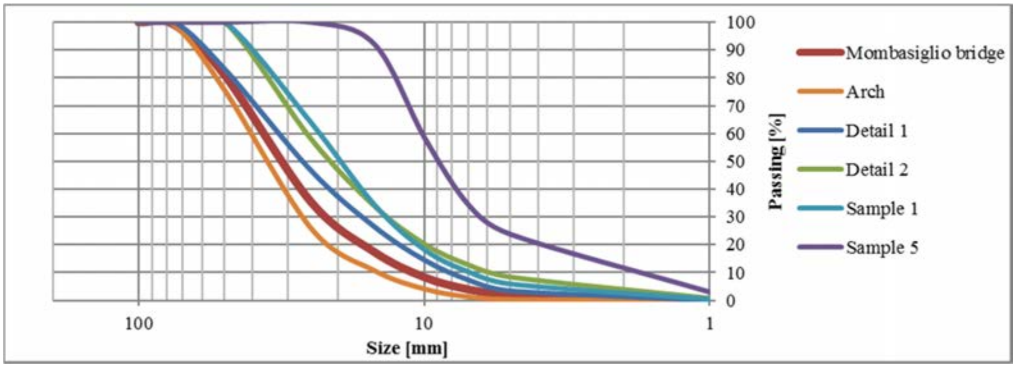

Fig. 4. Grain-size distribution curves for different considered scales of the rock mass.

3. Geophysical surveys

Combining electric and seismic data is a useful approach for a non-destructive assessment of material under study. The complementarity between electric and seismic methods is indeed favorable with respect to both the analysis of water content and of material resistance. Electrical resistivity is indeed very sensitive to fluid phases, while seismic wave velocity is more sensitive to the mechanical properties of the soil skeleton. Literature examples of the combined application of these two methodologies are reported in several papers (e.g. [11-13]) sometimes also with the use of joint inversion approaches (e.g. [14,15]). Particularly, the use of both methodologies together enabled us to have a first prelaminar understanding of the reasons for potential instabilities.

Owing to the limited available space, 4 parallel lines of 12 electrodes were adopted, with an average electrode spacing of 2.5 m. Both Dipole-Dipole and Wenner-Schlumberger arrays were acquired. Both single-cable and cross-cable acquisitions were performed in order to maximize lateral coverage and depth of investigation. Apparent resistivity data from both acquisitions were analyzed together. The maximum expected depth of the investigation is about 5 m which is coherent with the thickness of the arch crown. Data inversion in 3D was performed with ERTLab software. Refraction seismic acquisitions were carried out with a geophone array analogous to the electrode disposition. Several (21) shot positions were adopted and seismic P waves were registered by means of 48 30-Hz geophones (at 2.5 m spacing) with a recording time of 256 ms and a sample interval of 20.8 µs. Manual first break picking of all the shots was performed with on-purpose-developed Matlab routines. These data were inverted in tomographic approach by means of the GeoTomCG software which performs three-dimensional tomographic analysis with source and receiver positions in any configuration within a 3-D mesh.

Electrical resistivity results draw a variable field showing a more resistive volume (> 700 Ωm) in the SE part (upstream) and a more conductive one (< 300 Ωm) on the NW (downstream). Samples of the conglomeratic material were also analyzed at the lab scale and a mean resistivity value of about 2000 Ωm was found in dry condition. Therefore a significant amount of water is supposed to be present in natural conditions with an increasing water content on the downstream side of the bridge. Both primary and secondary porosity seem to drive water movement within the rock mass. Seismic data inversion depicted lower p-wave velocities (600-800 m/s) in the shallower underground portions, particularly in the center of the bridge and close to the small slide located on the eastern part of the left abutment. A velocity reduction is also noted in the north-western side of the bridge, reflecting a lack of lateral confinement particularly relevant on this side. Generally, over the whole model, bridge plane shows lower velocities (< 1200 m/s) than the abutments (> 1600 m/s) and the NW side (downstream) confirmed to be the most altered (together with the landslide zone), since velocity is still less than 1000 m/s up to almost the end of the model.

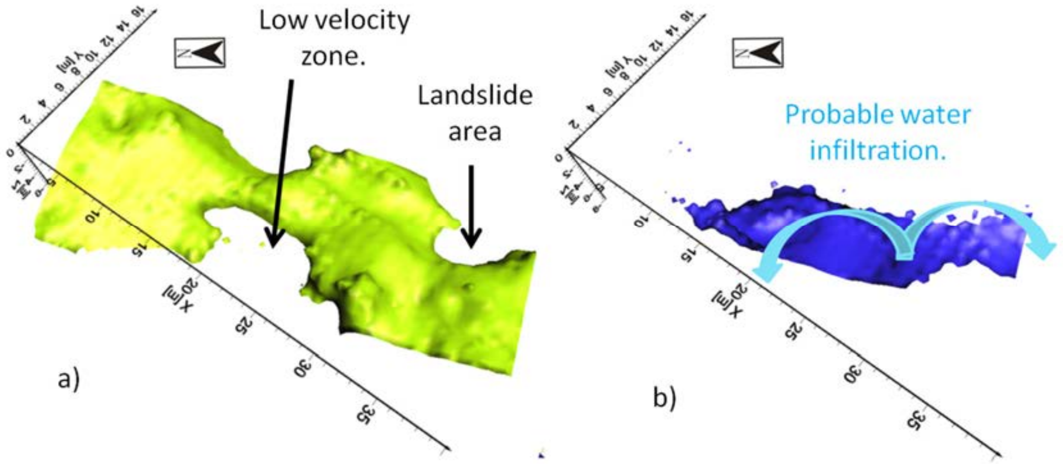

Fig. 5. 3D view of the a) high velocity (1600 m/s, in green) and b) low-resistivity (150 Ωm, in blue) isosurfaces from the inverted models.

Water infiltration due to rainfalls equally fills the pore spaces and flows along the possible discontinuities of the secondary porosity. Nevertheless, the highest Sun's radiation received by the SE part of the bridge (upstream) can generate moisture movement or even evaporation within the pores. This consideration can also explain the velocity field achieved by seismic inversion. The abutments have a similar velocity distribution, whereas the downstream part of the arch shows a localized low-velocity zone. Remarkably, the zone of the bridge where a slide already occurred has a similar velocity reduction. A driving mechanism for instability can be therefore supposed and related to water infiltration. In Figure 5, a 3D representation of the low-resistivity (150 Ωm) isosurface is reported together with the high-velocity (1600 m/s) isosurface. It can be observed that the high velocity zone of the model is truncated where there is evidence of lower resistivities and therefore higher water content which contributes to a reduction of the material competence.

4. Conclusions

The present paper discussed the preliminary results of an ongoing research aimed at characterizing a complex conglomeratic formation, in order to evaluate the stability conditions of a natural arch bridge. In situ and laboratory measurements are under development but a first evaluation of the rock REV has been done by the analysis of the grain size distribution, showing how the REV dimension overcame the laboratory specimens dimensions and nondestructive geophysical methodologies are consequently preferred. Combined 3D seismic and electrical surveys have been therefore applied to characterize the rock mass. Results presented enabled us to describe the rock-mass natural state and to suppose eventual instability mechanisms and causes. The consistency of the rock mass under examination can be hypothesized to be driven by the presence of water within the pore spaces and related to the exposure to Sun's radiation. Further laboratory tests are planned to have a confirmation of these geophysical findings.

Acknowledgments

Authors wish to thank Aldo Michelotti and Enzo Errani for their special attention to environment and historical aspects of the work.

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