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An integrated multiscale approach for characterization of rock masses subjected to tunnel excavation

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A B S T R A C T

The design of tunnels must be conducted based on the knowledge of the territory. The longer the structure, the larger the area to be investigated, and the greater the number of surveys and tests to be performed in order to thoroughly examine all the relevant features. Therefore, optimization of the investigation process is strongly required to obtain complete and reliable data for the design of the infrastructure. The fast development of remote sensing technologies and the affordability of their products have contributed to proving their benefits as supports for investigation, encouraging the spreading of automatic or semi-automatic methods for regional scale surveys. Similarly, considering the scale of the rock outcrop, photogrammetric and laser scanner techniques are well-established techniques for representing geometrical features of rock masses, and the benefits of non-contact surveys in terms of safety and time consumption are acknowledged. Unfortunately, in most cases, data obtained at different scales of investigations are only partially integrated or compared, probably due to the missing exchange of knowledge among experts of different fields (e.g. geologists and geotechnical engineers). The authors, after experiencing such a lack of connection among the results of different surveys concerning tunnels, propose a multiscale approach for the optimization of the investigation process, starting from the regional scale, to obtain the data that can be useful not only for planning more detailed surveys in a preliminary phase, but also for making previsions on the discontinuity sets that are present in the rock masses subjected to excavations. A methodological process is proposed and illustrated by means of a case study. Preliminary results are discussed to highlight the potentiality of this method and its limitations.

1. Introduction

An in-depth knowledge of the geological aspects of the area in which a tunnel will be excavated is fundamental for optimizing the layout. In fact, costs, duration of the work and possible issues are strictly correlated to the geological, geomechanical and hydrogeological variables of the strata. The investigation process needs to be optimized to obtain complete and reliable data for the preliminary design of the infrastructure.

The stratigraphic, structural and hydrogeological settings can be preliminarily acquired from literature data, aerial and satellite images, particularly in case of scarce bibliography or limited accessibility of the area. Then, onsite surveys are usually performed to validate and integrate the data. During this step, information regarding the most favorable direction of the tunnel layout is inferred, and detailed surveys (geognostic investigations, geophysical surveys, etc.) to be performed along this direction are then planned to establish the definitive layout.

Anyway, the onsite survey alone could be insufficient to obtain the missing data due to the limited scale of observation, costs and duration of the operations and safety conditions. Therefore, particularly in the first steps of the design, the use of remote sensing technologies is fundamental, and their fast development and the affordability of their products have contributed to extensively proving their benefits as supports for geological lineaments identification (Clark and Wilson, 1994; Davis and Reynolds, 1996; Florinsky, 1998; Suzen and Toprak, 1998; Chorowicz et al., 1999; Morelli and Piana, 2006; Marghany and Hashim, 2010; van der Meer et al., 2012; Hashim et al., 2013), encouraging the spreading of automatic or semi-automatic methods for regional scale surveys (Deffontaines et al., 1994; Koike et al., 1995; Wladis, 1999; Tripathi et al., 2000; Mavrantza and Argialas, 2003, 2008; Ramli et al., 2010; Lee et al.,

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2012; Vaz et al., 2012; Soto-Pinto et al., 2013; Al-Obeidat et al., 2016). The need to overcome possible limitations of the use of satellite images due to the characteristics of sensor, landform, lighting and weather conditions (Shepherd and Dymond, 2003; Smith and Wise, 2007) has promoted the use of digital terrain models (DTMs) for lineament mapping (Ganas et al., 2005; Jordan et al., 2005; Masoud and Koike, 2006, 2011; 2017; Jacques et al., 2012; Seleem, 2013; Rahnama and Gloaguen, 2014; Bonetto et al., 2015).

In many cases, a repetition on a small scale of structural elements is observed at a regional scale. Rocks are able to record permanently the effects of one or more stress fields by deforming in a brittle or ductile way. For this reason, at regional scale, the effects of plate tectonics are revealed by folds and faults, affecting large portions of territory, which represent different evolutive phases of the tectonic history of the area. Those structures also influence the arrangement of local tectonics, where structural elements can be often observed, whose orientation is similar to those identified at regional scale. For example, a fold axis could produce a foliation parallel to the axial plane, visible at mesoscale and microscale; similarly, a significant fault could produce discontinuity sets parallel to it, visible at the scale of rock face. Therefore, regional scale investigation in preliminary design, if accurately performed, could give very useful information to make hypothesis and previsions on what one could expect to find at local scale. This is the main assumption of the integrated multiscale method presented hereinafter.

Once the definitive layout has been chosen, the final design requires creating a geological-technical section, in which homogeneous geological domains and their mechanical characteristics are defined. This will have to be continuously checked and updated during the executive phase. In fact, the design does not end till the tunnel is finished. Due to the complexity of the work, the great longitudinal extension and the consequent possible variability of the geological and geotechnical characteristics of the encountered materials, the Eurocode 7 (EN 1997-1:2004, 2004) permits the implementation of the observational method (Peck, 1969), which is a continuous, managed and integrated process of design, construction control, monitoring and review, enabling appropriate, previously defined modifications to be incorporated during (or after) construction (Nicholson et al., 1999).

In this paper, a semi-automatic method for linear features identification at regional scale (Bonetto et al., 2015) is applied to obtaining the information that can be useful for making previsions on the potential discontinuity sets encountered during the excavation. Then a non-contact method for surveying discontinuities orientation (Ferrero et al., 2009) is applied continuously to tunnel fronts in order to update the assumed geomechanical model, check design choices and validate the preliminary data obtained at regional scale. A methodological process is proposed and illustrated by means of an application to a portion of the tunnel called Finestra Val Lemme, a lateral access of the Terzo Valico tunnel. Preliminary results are discussed in order to highlight the potentiality of this method and its limitations.

2. The Finestra Val Lemme case study

The Rhine-Alpine Corridor constitutes one of the busiest freight routes of Europe, connecting the North Sea ports of Rotterdam and Antwerp to the Mediterranean basin in Genoa, via Switzerland and some of the major economic centers in the Rhine-Ruhr and Rhine-Main-Neckar regions and the agglomeration of Milan in Northern Italy (European Commission – Mobility and Transport, 2017). This north-to-south corridor will integrate Priority Projects 5 and 24, ERTMS Corridor A and Rail Freight Corridor 1.

Part of the Rhine-Alpine Corridor is represented by the high speed/high capacity railway from Milan to Genoa, denominated "Terzo Valico dei Giovi" (Terzo Valico, 2017), currently in progress. The layout covers an overall distance of 53 km (37 km in tunnels). It consists of two tubes, each being equipped with a single track. This means that train traffic through the tubes is one-way. The two tubes are linked by connecting side tunnels, which can be used in emergencies as escape routes. This configuration conforms to the highest security standards for tunnels. The tunnels will be mainly excavated by drill-and-blast method, except for some sections in which mechanical methods will be used. For construction and safety reasons, the main tunnel is intersected by four lateral access tunnels (Polcevera, Cravasco, Castagnola and Val Lemme). In particular, the Val Lemme one, currently being completed (Terzo Valico, 2017), is located on the right side of the Lemme Valley (Alessandria Province, Italy). It is about 1.7 km long, its direction is N102.28°, and the maximum cover height is 240 m. The excavation process was carried out following the design criteria of the ADECO-RS method (Lunardi, 2006, 2008). The Finestra Val Lemme tunnel was dug in the "Argilloscisti di Costagiutta" and "Argilloscisti di Murta" formations (Fig. 1). They consist of dark gray shale with pervasive schistosity characterized by the presence of small-spacing and graphite-sericite coats caused by fluid circulated during deformation stages (Capponi et al., 2008).

3. Regional scale investigation

CurvaTool code (Umili et al., 2013; Bonetto et al., 2015) has been developed considering the following assumption: on a DTM, a geological lineament can be geometrically identified as a convex or concave edge, particularly where there is evidence of a structural control of the geomorphological evolution of the analyzed area.

CurvaTool performs the identification of all the significant linear features of a DTM, e.g. polylines composed of points whose principal curvature values are above the thresholds assigned by the user (this method is called semi-automatic because the user is asked for two thresholds, and then the linear features extraction procedure is automatic) (Umili et al., 2013). Next, the obtained database can be statistically analyzed according to the geological knowledge of the area, in order to identify the orientation, length and spatial distribution of the lineaments. Post-processing performed by Filter code (Bonetto et al., 2015) can follow two different approaches: if no literature data are available for the studied area, the resulting rosette of directions can be used to make observations useful for a preliminary tectonic assessment. Instead, if the mean directions of lineaments sets are known, Filter code classifies each edge, attributing it to the correspondent input cluster.

By plotting the obtained database on the DTM, domains characterized by different deformation styles could be recognized. The overall positive aspects of this semi-automatic process were found to be the informativeness on geological structure for preliminary geological assessment and set identification, the possibility to identify the most interesting portions of the area to be investigated, and the possibility to analyze zones that are not directly accessible (Bonetto et al., 2015). Certainly, a residual possibility that some of the extracted linear features could be false lineaments, namely natural or artificial linear elements that do not represent geological lineaments, exists and must be taken into account. However, this is reduced by two conditions: lineaments whose dimensions are smaller or similar to the ground resolution are not – or only partially – represented by the DTM; moreover, the most common artificial linear elements, such as roads and railroads, are almost flat and therefore, even if detectable on the DTM surface, they belong to regions with non-significant curvature values. Since the purpose of the application of CurvaTool is not only to create a lineament map, but also to obtain information about the average direction of lineament sets, a single false lineament cannot invalidate the result of a

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