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Applying rock mass classifications to carbonate rocks for engineering purposes with a new approach using the rock engineering system

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ABSTRACT

Classical rock mass classification systems are not applicable to carbonate rocks, especially when these are affected by karst processes. Their applications to such settings could therefore result in outcomes not representative of the real stress–strain behavior. In this study, we propose a new classification of carbonate rock masses for engineering purposes, by adapting the rock engineering system (RES) method by Hudson for fractured and karstified rock masses, in order to highlight the problems of implementation of geomechanical models to carbonate rocks. This new approach allows a less rigid classification for carbonate rock masses, taking into account the local properties of the outcrops, the site conditions and the type of engineering work as well.

1. Introduction

During the preliminary design stages of a project, information on rock masses, in terms of strength, deformability, in situ stress and hydrologic characteristics, is not greatly detailed, and the rock mass classification system is the most common approach used for solving rock engineering purposes. It is a common practice to use, for any rock engineering application with different boundary conditions and geometries, multi-parameter classification schemes, such as those proposed by Bieniawski (1973, 1974, 1989, 1993) and Barton et al. (1974), without due consideration of the original aims for which these systems were developed, and the engineering geological characteristics of the rock mass as well (Fookes, 1997; Jing, 2003; Andriani and Parise, 2015; Parise et al., 2015a). The majority of the available schemes use a defined number of parameters, to which ranges of value are assigned, based upon in situ surveys, or laboratory and field tests (for instance, attitude, discontinuity conditions, uniaxial compressive strength, and rock quality designation (RQD)). This approach is highly useful to solve many engineering geological problems, but, on the other hand, it is too rigid when dealing with particular situations (e.g. slope instability and foundations), especially when rock masses not exactly responding to the original criteria of the scheme are dealt with. This is certainly the case for carbonate rock masses, which are particularly sensitive to syn-depositional and post-depositional diagenesis, including dissolution and karstification processes, cementation, recrystallization, dolomitization and replacement by other minerals. Furthermore, as sedimentary rocks, carbonate rocks are typically stratified, laminated, folded, faulted and fractured. As a consequence, a carbonate rock mass is characterized by inherently anisotropic properties (physico-mechanical, hydraulic, dynamic, thermal). Anisotropy can be found at different scales in carbonate rocks ranging from intact specimens to the entire rocks. The strength and deformability of carbonate rock masses depend, therefore, on those of the intact blocks and on their freedom of movement which, in turn, are affected by the discontinuities, as well as by their pattern, orientation and infilling. For a complicated case, the development of karst features, showing irregular geometry, has to be added (De Waele and Parise, 2013). Eventually, the scale of the engineering problem determines the choice between a continuum model and a discontinuum model to represent the rock mass behavior at the stage of design analysis. Such a choice is of extreme importance, and should be derived from the knowledge acquired during the engineering geological characterization of the rock mass (Barla and Barla, 2000; Jing and Hudson, 2002; Andriani, 2015).

Due to the presence of karst features, either active or related to paleo-karst, implementation of the main classification schemes to carbonate rock masses has several problems (Fig. 1). Furthermore, other complications are related to the stratigraphic and structural settings, and to lack of a parameter in the classification schemes

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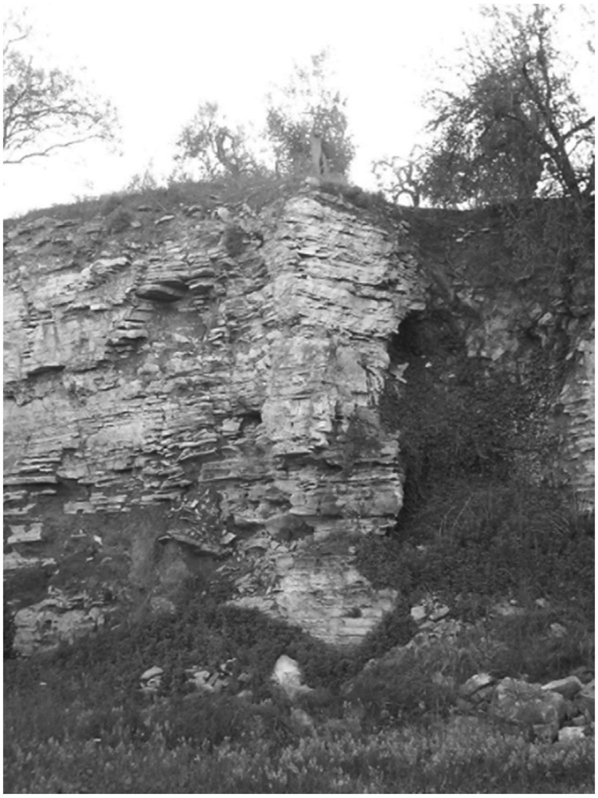

Fig. 1. Quarry wall in thinly bedded Cretaceous limestone, deeply karstified, with sub-horizontal conduits and caves.

which could account for the time effect on the strength and deformability properties of the rock masses (i.e. creep) (Scholtz, 1968; Dusseault and Fordham, 1993; Benardos and Kaliampakos, 2004). Experiences from underground calcarenite quarries have shown that the stability degree of pillars and vaults within the quarries decreases with time, as an effect of creep on the total strength of the rock mass (Bruno et al., 2007; Parise and Lollino, 2011; Lollino et al., 2013; Pepe et al., 2013). This effect is particularly significant in humid or wet sites, and for soft rock mass with high water content (Andriani and Walsh, 2002, 2007, 2010; Ciantia and Hueckel, 2013).

A further problem to be considered is overrating the proneness to instability by classical methods as the rock mass rating (RMR) by Bieniawski or the Q-system by Barton, as an effect of the correction factors of the discontinuity attitude. The same trend, even though less marked, characterizes the slope mass rating (Romana, 1985), derived from the original RMR. An interesting possibility, alternative to the classical methods, is the rock engineering system (RES) (Hudson, 1992). RES focuses upon the objective: this means that elements and interactions to consider may be adapted to the setting, the aim of the study, and the goal of the project. At the same time, the details needed to characterize the system, its elements and interactions, may change, too. RES so far has been successfully applied in several fields, including slope stability (Mazzoccola and Hudson, 1996; Calcaterra et al., 2004; de Luca Tupputi Schinosa, 2008; Andriani et al., 2009).

In this paper, we present an adaptation of RES to the classification of carbonate rock mass in karst environments. The approach aims at defining a practical model for simulating the behavior of karstified rock masses for engineering purposes, with particular regard to stability analyses of natural and man-made walls in carbonate rocks.

2. Methodology

The RES approach was first introduced by Hudson (1992) for the analysis of complex engineering problems in rock mechanics applications, including the stability of natural and artificial slopes, tunnels, underground quarries and caves (Mazzoccola and Hudson, 1996; Andrieux and Hadjigeorgiou, 2008; Budetta et al., 2008; Naghadhei et al., 2011; Palma et al., 2012a,b; Rafiee, 2014).

The approach is inspired to the general theory of the systems by von Bertalanffy (1950, 1968), according to which a system is defined as "a complex of elements in interaction", and later by Hall and Fagen (1956), according to which a system is "a set of objects together with relations between the objects and their attributes", where the objects are the components or parts of the system, the attributes are the properties of the objects, and the relationships "tie the systems together".

The first application of the systematic model in geomorphology dates back to Strahler (1980). Hudson and Harrison (1992) considered that in rock mechanics modeling and rock engineering design for a specific project, it is necessary to consider not only the individual parameter of the system but also how these parameters all interact together. At this goal, identification of all the relevant parameters of the system, corresponding to the physical variables, and the linking mechanisms are important, and their combined operation has to be considered. In practice, a general understanding of a rock engineering problem includes not only the primary mechanisms and factors, but also the interactions between them.

Although the RES approach is general and widely applicable, in each location and for each specific purpose, the description of the rock mass is fitted to the physical reality and to the engineering problem.

The RES approach is a systematic method in which the interactions between the various parameters of the system are listed in a matrix. The principal parameters considered relevant to the problem are listed along the leading diagonal of a square matrix (top left to bottom right) and the interactions between pairs of principal factors form the off-diagonal terms. The interaction between the parameters is then analyzed with a clockwise influencing convention. Generally, the influence of a parameter on the other is different, which means that the matrix is, in general, asymmetrical. This asymmetry is associated with the fact that the interaction depends on the path. The assigned values to off-diagonals are called "coding the matrix". Several methods have been developed for numerically coding the interaction matrix, such as the 0–1 binary, expert semi-quantitative (ESQ) method (Hudson, 1992) and the continuous quantitative coding (CQC) method (Lu and Latham, 1994). The most common coding method is the ESQ in which only one value is deterministically assigned to each interaction. Therefore, it is implicitly considered that there are no uncertainties when the influence of one parameter on the others is expressed in the matrix. Typically, the following coding values between 0 and 4 are employed with ESQ coding schemes: no, 0; weak, 2; medium, 3; strong, 4; and critical, 5. However, such coding values are not always constant and/or certain, depending on the type of problem. In other words, it is always possible that the coding value needs to be updated and/or modified under the specific conditions of a project, and, in many cases, it is also possible that an exact (and unique) digit-code cannot express the correct particular interaction. This could be due, for instance, to uncertainties in the assignment of values or even due to uncertainties on the physics of the problem (Naghadhei et al., 2011).

The main parameters (P_i) were listed along the leading diagonal of the matrix, as highlighted in Fig. 2. The row passing through P_i represents the influence of P_i on all the other parameters in the