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Prediction of the mechanical behavior of the Oporto granite using Data Mining techniques

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ABSTRACT

The determination of mechanical properties of granitic rocks has a great importance to solve many engineering problems. Tunnelling, mining and excavations are some examples of these problems. The purpose of this paper is to apply Data Mining (DM) techniques such as multiple regressions (MR), artificial neural networks (ANN) and support vector machines (SVM), to predict the uniaxial compressive strength and the deformation modulus of the Oporto granite. This rock is a light grey, two-mica, medium-grained, hypidiomorphic granite and is located in Oporto (Portugal) and surrounding areas. Begonha (1997) and Begonha and Sequeira Braga (2002) studied this granite in terms of chemical, mineralogical, physical and mechanical properties. Among other things, like the weathering features, those authors applied correlation analysis to investigate the relationships between two properties either physical or mechanical or physical and mechanical. This study took the data published by those authors to build a database containing 55 rock sample records. Each record contains the free porosity (N_{48}), the dry bulk density (d), the ultrasonic velocity (v), the uniaxial compressive strength (σ_c) and the modulus of elasticity (E). It was concluded that all the models obtained from DM techniques have good performances. Nevertheless, the best forecasting capacity was obtained with the SVM model with N_{48} and v as input parameters.

1. Introduction

Uniaxial compressive strength and modulus of elasticity are very important parameters in the analyses of rock masses behavior. These parameters are used to study underground and surface mining, slope stability, drilling and blasting and mechanical rock engineering (Tiryaki, 2008). Furthermore, they assume great importance in analytical and numerical solutions.

To take into account the many factors that affect the strength and deformability of rock masses, large scale in situ tests should be performed. Because such tests are very expensive and consume a lot of time, the unconfined compressive lab tests are an alternative to them. However, even the latter tests require a heavy frame and a careful preparation of the rock cores and continue to be more expensive and time consuming than other tests based on index properties. These easier and faster tests have been performed to obtain index properties that can be correlated both with uniaxial compressive strength (σ_c) and modulus of elasticity (E).

Irfan and Dearman (1978) presented correlations for granites between the uniaxial compressive strength and density, the effective porosity and the uniaxial compressive strength, the Young's modulus and effective porosity and the Young's modulus and sonic velocity. Christaras, Auger, and Mosse (1994) compared dynamic methods for the determination of modulus of elasticity with direct static methods for different types of French rocks. They used the mechanical resonance frequency and ultrasonic velocity techniques and concluded that these non-destructive methods are suitable for the determination of static modulus of elasticity. Kahraman (2001) presented correlation between uniaxial compressive strength values and the corresponding results of point load, Schmidt hammer, sound velocity and impact strength tests. He presented a nonlinear relationship between sound velocity and uniaxial compressive strength with a coefficient of correlation of 0.83. However he advised that the prediction is more reliable at low strength than at higher strength because the points are more dispersed at higher values. Begonha (1997) and Begonha and Sequeira Braga (2002) studied the mineralogical, chemical and geotechnical features of the granitic residual soils of the Oporto granite, the physical properties of the granitic rock, as well as the weathering effect in the geotechnical and physical properties.

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Those authors showed that all the properties of the Oporto granite are strongly affected by the weathering process. Arel and Tuğrul (2001) studied the weathering and its relation to geomechanical properties of granitic rocks from Turkey. They present several correlations between point load index, uniaxial compressive strength, slake durability, porosity, loss on ignition, dry and saturated unit weight and water properties. Tuğrul (2004) studied the changes in pore characteristics of different types of rock from Turkey due to weathering and presented relationships between both total and effective porosity and other engineering properties. Sharma and Singh (2007) presented a table with many relationships between P-wave velocity and uniaxial compressive strength reported by several researchers with coefficients of correlation (r) between 0.531 and 0.880. They also presented their own empirical relation for seven types of rocks with a coefficient of correlation of 0.9022. They concluded that P-wave velocity is a reliable method for estimating not only σ_c but also impact strength index and slake durability index. Kiliç and Teymen (2008) used non-destructive and indirect methods to estimate the mechanical properties of rocks by statistical equations. They tested nineteen different rock types and pointed out satisfactory correlations between shore hardness, point load index, sound velocity, Schmidt hardness and porosity and uniaxial compressive strength, indirect tensile strength and abrasion resistance. They presented nonlinear correlations between σ_c and V_p ($R^2 = 0.94$) and uniaxial compressive strength and the porosity ($R^2 = 0.93$). However, the authors advertised that equations may not be suitable for rocks with very low porosity (<2%).

The use of correlations like those mentioned above, should many times lead to unsatisfactory forecasts. To overcome this problem, artificial intelligent tools such as Data Mining techniques can be useful to build more accurate predictive models. The Data Mining is a step in the overall process of discovering useful knowledge from databases and consists in the application of suitable algorithms or techniques to extract knowledge from data and obtain a pattern or model. Neural networks and support vector machines are examples of DM algorithms. The ANN technique is the most widely used technique in the rock engineering domain. It has been used to build models to identify probable failure on rock masses (Guo, Wu, Zhou, & Yao, 2003), for rock classification (Millar & Hudson, 1994), for prediction of uniaxial compressive strength (Dehghan, Sattari, Chehreh Chelgani, & Aliabadi, 2010; Singh, Singh, & Singh, 2001; Zorlu, Gokceoglu, Ocakoglu, Nefeslioglu, & Acikalin, 2008), tensile strength (Singh et al., 2001), modulus of elasticity of rocks (Dehghan et al., 2010; Majdi & Beiki, 2010; Miranda, Gomes Correia, Santos, Ribeiro e Sousa, & Cortez, 2011), the weathering degrees of rocks (Dagdelenler, Sezer, & Gokceoglu, 2011; Gokceoglu, Zorlu, Ceryan, & Nefeslioglu, 2009), etc. This technique is based on the functioning of the human nervous system and can handle data with complex relationships that can be strongly nonlinear. Support vector machines are alternative techniques to the ANN but scarce applied in rock engineering. Like the ANN, the SVM has a high degree of complexity. These DM techniques and the traditional multiple regression were used in this study to build models to forecast the σ_c and E of granitic rocks from Oporto, Portugal. As far as we know, SVM has not yet been applied to predict both σ_c and E of granitic or other rocks.

2. Materials and methods

2.1. Petrographic characterization

The studied rock, named the Oporto granite, is a light grey, two-mica, medium-grained, hypidiomorphic granite and is located in Oporto and surrounding areas. It is composed by quartz, microcline (k-feldspar), plagioclase muscovite and biotite. Muscovite is the dominant mica and microcline is frequently perthitic. Apatite, zircon and rutile are the accessory minerals. The fresh rock was submitted to a late post-magmatic alteration, being characterized by several generations of dioctahedral micas, chlorite, rare chlorite-smectite mixed-layer minerals and a pure smectite phase (Begonha, 1997; Begonha & Sequeira Braga, 2002).

Climatic conditions of NW Portugal favor the granite weathering and its outcrops often display different degrees of weathering. Total weathering profile depths frequently exceed 20–30 m and granitic saprolites can be more than 10 m thick.

Clay minerals and associated minerals that characterize the bulk weathered rock and granitic saprolites are kaolinite, gibbsite, and chlorite-vermiculite mixed-layer (Begonha, 1997; Begonha & Sequeira Braga, 2002). According to these authors the amount of plagioclase is significantly reduced at the very beginning of the weathering process (weathered rock). On the contrary, the relative increase of the microcline at the earlier stages of the weathering process and the decrease in later ones, indicate its higher resistance to weathering compared to plagioclase.

2.2. Granite weathering effects in physical properties

In this paper some of the more significant works on the Oporto granite (Begonha, 1997; Begonha & Sequeira Braga, 2002) will be reviewed, from the particular context of the weathering effect in the physical properties of the granite.

The granite weathering was studied in order to obtain a physical property to be used as an index of the degree of weathering and to estimate other properties. Several tests were performed in order to obtain total porosity (N_T), free porosity (N_{48}), dry bulk density (d), ultrasonic velocity (v), uniaxial compressive strength (σ_c), modulus of elasticity (E) and strain in rupture (ε). Table 1 presents the results published by Begonha (1997) that were used in this study and Table 2 shows the statistical assessments of the parameters of Table 1.

The ISRM (1978) classification was used and rocks were classified as fresh (W1) to moderately-highly weathered (W3-W4) (Table 1). As it can be seen, most of the rocks are moderately weathered with less than half of the rock decomposed (W3).

Table 2 shows that the free porosity (N_{48}) presents the higher coefficient of variation and the dry bulk density (d) the lower. Therefore, N_{48} presents the greater variability and d the lower variability. The other parameters present similar variability.

Among several nonlinear relationships between two physical parameters carried out by Begonha (1997) only σ_c and E (engineering properties) will be treated in this study (Table 3). This study aimed to build more accurate models based on powerful techniques to forecast σ_c and E from other physical properties. To achieve this goal, DM techniques such as ANN, SVM and MR were used.

Figs. 1 and 2 show the histograms of the uniaxial compressive strength and of the modulus of elasticity, respectively. It can be seen that most of the data have values of σ_c between 60 and 120 MPa and values of E between 6 and 12 GPa.

2.3. Data Mining

In this study the Data Mining process was applied to predict the uniaxial compressive strength and the modulus of elasticity. Artificial neural networks, support vector machines and multiple regressions were applied. It was used the environment R (R Development Core Team, 2010) with the RMiner library developed by Cortez (2010) and some available packages. The library RMiner presents a set of functions that make easier the use of DM algorithms both in classification and regression tasks. Both tasks require a