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The influence of fabric and water content on selected rock mechanical parameters of travertine, examples from Hungary

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ABSTRACT

Two types of Hungarian travertine a massive less porous and a laminated porous type were tested under laboratory conditions. Tests aimed to assess the performance and durability of the stone to be used as replacement stone in reconstruction works. Analyses included the determination of density, ultrasonic wave velocity, effective porosity and the uniaxial compressive strength of both air-dry and water saturated specimens. The mechanical and physical properties have been compared and the relationships between the different petrophysical constituents have been analyzed by using statistical methods. Linear correlation was found between density and ultrasonic pulse velocity of both dry and saturated samples. According to regression analyses uniaxial compressive strength and ultrasonic pulse velocity; effective porosity and ultrasonic pulse velocity are exponentially related. The fabric and especially the porosity have the highest influence on the strength and durability of travertine. Tests have demonstrated that massive low porosity travertines with relatively homogenous micro-fabric have higher strength and ultrasonic pulse velocity than less homogenous laminated types. By using the equations of statistical analyses it is possible to assess the strength of travertine in the field applying standard non-destructive tests.

1. Introduction

Travertine is a common building and dimension stone that has been explored and used in many countries (Pentecost, 2005) from as early as prehistoric times. Travertine was one of the favourite stones of the Roman Empire (e.g. Colosseum in Rome) but emblematic monuments and modern structures are found worldwide (e.g. J. Paul Getty Museum Conservation Center in Los Angeles). Besides Italian travertine famous occurrences are known in Europe (e.g. from Germany, Hungary) and from Asia (Turkey, Kahraman et al., 2004). Travertine is considered a durable stone although air pollution related weathering is commonly observed and black crust covered façades are common in urban areas (Sindraba et al., 2004; Török, 2006a, 2008). Travertine is not a homogenous rock type in terms of fabric, since porosity and sedimentary structures show some variations. Several previous studies have shown that fabric and petrography of rocks are important factors in controlling mechanical properties of various rock types. The effect of grain size and shape (Haney and Shakoor, 1994; Wong et al., 1996; Přikryl, 2001), porosity (Hatzor and Palchik, 1997; Török, 2006b; Sabatakakis et al., 2008) and mineral composition (Tsiambaos and Sabatakakis, 2004; Sabatakakis et al., 2008) on strength and crack propagation were analyzed for many lithologies, but very few data available for travertines. The present paper tries to bridge this gap of information by focusing on the mechanical properties of Hungarian travertine with special emphasis on the influence of fabric and water content on the mechanical properties. The practical application of this data set is related to the use of the travertine as building and/or replacement stone. By correlating physical properties of dry and water saturated samples it is possible to find relationships that help in predicting the long term behaviour and durability of travertine and the selection of proper quality blocks at quarry level.

2. Theoretical background

Several studies have investigated rock strength (i.e. uniaxial compressive strength, UCS) variation by a number of petrophysical factors, such as mineral composition (Price, 1966; Sabatakakis et al., 2008), density (Smorodinov et al., 1970; Hecht et al., 2005), porosity (Dunn et al., 1973; Hoshino, 1974; Onodera et al., 1974; Kelsall et al., 1986; Palchik, 1999; Li and Aubertin, 2003; Benavente et al., 2004; Ván, 2004) and fabric (Onodera and Kumara, 1980; Přikryl, 2001; Török, 2006b). The influence of moisture content on the strength and deformability of sedimentary rock types was reported in detail by Colback and Wiid (1965). Relationships between moisture content and changes in physical properties were found for shale lithologies and quartzitic sandstones by Van Eeckhout and Peng (1975) and for sandstones by Hawkins and McConnell (1992) but no such data

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available for travertines. According to the results of Přikryl (2001), with increasing porosity UCS decreases logarithmically. However, investigating the relationship between porosity and rock strength Palchik (1999) has found the following correlation:

$$UCS = mE\,/\,n, \tag{1}$$

where m is a material constant, E is the elastic modulus and n is the porosity.

Smorodinov et al. (1970) were the first to apply the exponential relationship between UCS and bulk density for different dolomite and limestone types under dry conditions. None of these studies investigated the influence of water.

After measuring 35 different types of British sandstone, Hawkins and McConnell (1992) first determined a negative exponential function between UCS and water content:

$$UCS = a\exp(-bw) + c, \tag{2}$$

where w is the water content, a, b and c are material constants. Their results were also analyzed by Vásárhelyi (2003) and Vásárhelyi and Ván (2006). Previously similar approaches were made to analyze the strength and deformation of various lithologies under dry and water saturated conditions (Romana and Vásárhelyi, 2007). Besides sandstones, volcanic tuffs (Vásárhelyi, 2002; Kleb and Vásárhelyi, 2003) and porous limestones (Vásárhelyi, 2005) were also analyzed. By using regression analysis of different petrophysical constants (i.e. Young's modulus-UCS, UCS-tensile strength) these papers have demonstrated that the correlation between these parameters is possible without considering the water content of the tested samples.

3. Material

The studied travertine comes from North Hungary, close to river Danube at the village of Süttő (Fig. 1a). The present quarry exposes travertine, which was deposited from lukewarm springs during the Pleistocene period (Korpás, 2003) and it is very similar to the ones of Italy and Turkey in terms of the origin, since it was also precipitated from lukewarm waters and less porous and more durable than calcareous tufas of recent or sub-recent stream deposits. There are evidences that quarrying activity in the area has already begun during the reign of the Roman Empire (1st century BC to 4th century AD, Török, 2007). The travertine than was used for constructing aqueducts, fortresses, amphitheatre (1st to 3rd century AD). In these days the travertine from Süttő quarry is exploited for using as ashlars, polished slabs and ornamental stones as well as artistic elements. This locality provides replacement stones for the reconstruction works of several monuments in Hungary, including the Parliament building in Budapest (Fig. 1b). The 20-metre thick deposit is not uniform it contains various lithotypes related to changes in the depositional environment and water supply of springs (Korpás, 2003; Török, 2003). The quarrying activity is mostly focused on two main lithotypes with different fabric: i) massive less porous travertine (Fig. 1c) and ii) laminated porous travertine (Fig. 1d).

For the rock mechanical tests 40 blocks were selected from the quarry. The blocks were taken from the rock storage facility of the quarry. These blocks come from those that were pre-selected as replacement stone for the reconstruction works of the Parliament House, Budapest. The block size was of 20 cm*25 cm*40 cm. Prior to mechanical tests the fabric of each block was identified and recorded according to Török (2008).

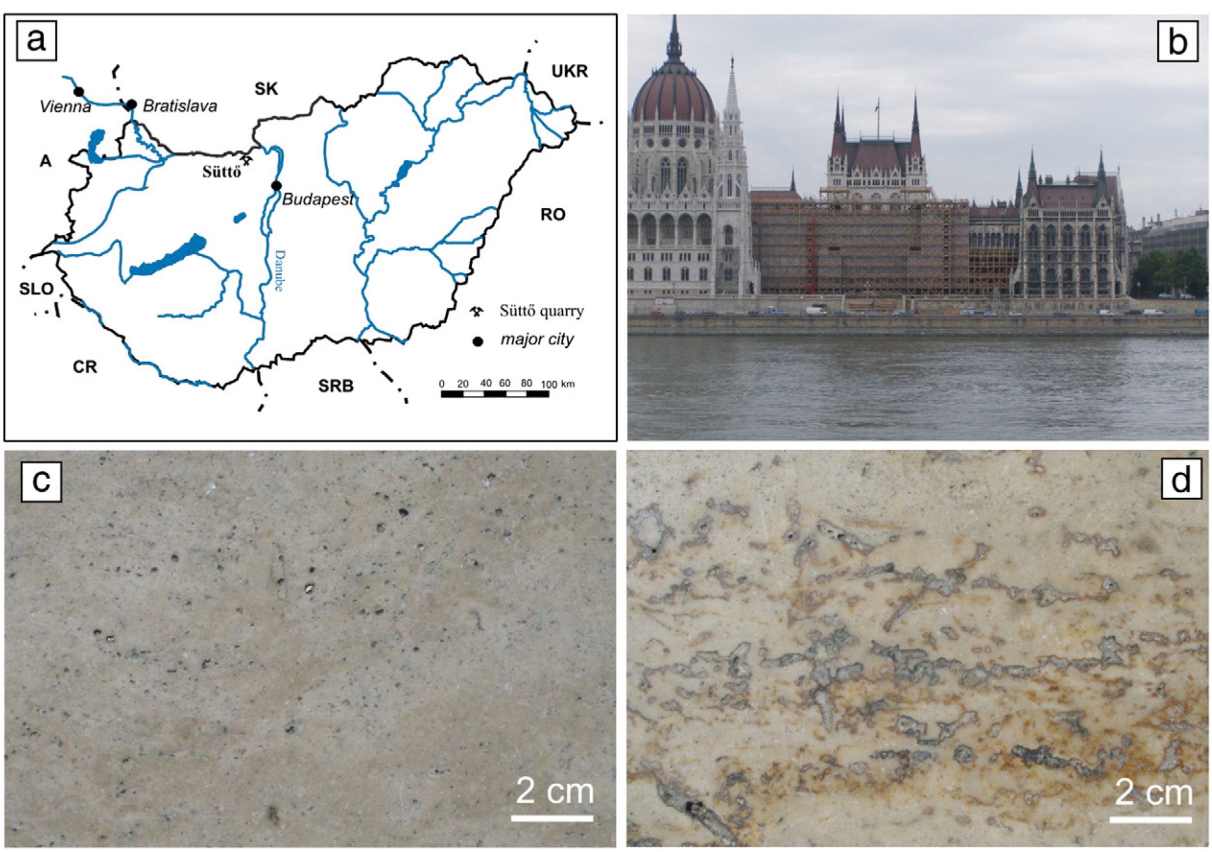

Fig. 1. (a) Map of Hungary showing the location of Süttő travertine quarry; (b) the western façade of Houses of Parliament in Budapest with scaffolds where travertine is used as replacement stone; (c) massive travertine; and (d) laminated porous travertine.