Estimation of uniaxial compressive strength and water permeability from elastic waves measurements in sedimentary stones

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Uniaxial compressive strength (UCS) and water permeability (WP) are two of the most critical petrophysical parameters used in many fields of engineering and geosciences. Particularly, in stone conservation studies, these parameters are closely related to stone stability and durability in monuments. Although stone conservation studies can require large data sets, many have limited access to samples, and so require non-destructive on-site characterisation of UCS and WP.

Non-destructive methods (NDT) based on elastic wave measurements are commonly used in stone conservation studies and can be performed in both laboratory and field experiments. Experimentally, P-waves are easy to generate and acquire, whereas the generation and acquisition of pure S-waves in rocks can be difficult. Moreover, other ultrasonic parameters from the analysis of the recorded output waveform (mostly of the P-waves) can be extracted. These additional parameters provide complementary information from the same measurement performed for the calculation of P-wave velocity.

In this paper, we estimate USC and WP by combining connected porosity and ultrasonic parameters recorded from P- and S- waves for a wide range of carbonate sedimentary rock types. Fifteen rock samples were measured including calcarenites, sandstones, dolostones and travertines. These rock types are building stones quarried in Spain and were selected based on their different petrophysical and petrographic characteristics.

The ultrasonic measurements were carried out using the transmission method, which consists of two piezoelectric sensors (1 MHz Panametric transducers) coupled to the sample at constant pressure. We determine the onset of P- and S-waves considering signal pre-processing and the analysis of the recorded signals. We calculated P- and S-wave velocities, and the spatial attenuation and the wavelength of the first pulse of P-waves. Statistical analysis was applied to establish the structure of the variable dependence and their interrelationship using the code SPSS 22.0. Statistical analysis includes scattering diagrams and Pearson’s correlation coefficients, a principal component analysis, and a stepwise multiple regression analysis.

Mineralogical composition, porosity and particle size affect the wave velocity, attenuation, wavelength and waveform, which can be used as a selection criterion of parameters in the predictive functions. Results reveal that mineralogical composition significantly affects P-wave velocity values, especially for quartz-bearing rocks. Grain size is also reflected in the waveform. Thus, coarse-grained rocks have the highest wavelength and spatial attenuation. Spatial attenuation is a parameter sensitive to occasional rock defects such as the vuggy porosity observed in travertines. UCS and WP strongly depends on this type of vuggy porosity and how the vuggy porosity is connected.

Several simple and multiple predictive expressions for UCS and WP are fitted, which are quantified

through the Pearson correlation coefficient (R). Curve fitting improves as the number of petrophysical parameters increases in the multiple linear regressions. The best correlation is found when the predictive equation incorporates all the elastic wave parameters obtained non-destructively and connected porosity for UCS (R=0.921) and WP (R=0.903). Spatial attenuation is the most significant variable of the elastic wave parameters of the fitted regressions, and its addition into multiple linear equations causes an increase of goodness of fit. Connected porosity also improves R whereas wavelength and P-wave velocity have a lower statistical weight in the predictive expressions. The UCS and WC estimation from all NDT, without considering connected porosity, shows a good correlation (R=0.852 and 0.864, respectively). This study shows that UCS and WC can be obtained non-destructively using portable equipment and can provide large data sets at a relatively low cost.

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