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LABORATORY TESTING PROPERTIES OF SANDSTONES

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Abstract

The aim of this paper is to determine the geotechnical properties of clastic sedimentary rocks and especially sandstones which constitute a great part of the flysch formation. Laboratory tests were conducted in samples collected from different sites in western Greece. Physical and mechanical properties were determined including porosity (n), dry density (ρ_d), sound velocities (V_p, V_s), point loading strength ($I_{s(50)}$) and uniaxial compressive strength (σ_c). Additionally, the material constant m_i, an input parameter for the Hoek and Brown failure criterion, was estimated by analyzing the results from a series of triaxial compression tests under different confining pressures. Regression analyses were also applied to define the relations among the obtained parameters.

Key words: *dry density, porosity, sound velocity, uniaxial compressive strength, rock material.*

Περίληψη

Σκοπός της εργασίας αυτής είναι η εκτίμηση των γεωτεχνικών παραμέτρων του βραχώδους υλικού των ψαμμιτών που συνιστούν ένα σημαντικό τμήμα των σχηματισμών του φλύσχη. Εκτελέστηκε ένας σημαντικός αριθμός εργαστηριακών δοκιμών Βραχομηχανικής σε δείγματα ψαμμιτών από διαφορετικές περιοχές της δυτικής Ελλάδας. Υπολογίστηκαν οι φυσικές και μηχανικές παράμετροί τους και συγκεκριμένα το πορώδες (n), το ξηρό φαινόμενο βάρος (ρ_d), οι ταχύτητες διάδοσης των υπερήχων (V_p, V_s) καθώς επίσης και οι αντοχές σε σημειακή φόρτιση ($I_{ς(50)}$) και σε μοναξονική θλίψη (σ_c). Επίσης προσδιορίστηκε η σταθερά m_i που χρησιμοποιείται στο κριτήριο θραύσης των Hoek και Brown, ύστερα από ανάλυση αποτελεσμάτων δοκιμών τριαξονικής φόρτισης σε διαφορετικές πλευρικές τάσεις. Τέλος, έγινε στατιστική επεξεργασία των παραπάνω παραμέτρων και εκτιμήθηκαν εμπειρικές σχέσεις μεταξύ των φυσικών και μηχανικών χαρακτηριστικών του βραχώδους υλικού.

Λέξεις κλειδιά: *ξηρό φαινόμενο βάρος, πορώδες, ταχύτητα υπερήχων, αντοχή σε μοναξονική θλίψη, βραχώδες υλικό.*

1. Introduction

The strength of intact rock is one of the main mechanical characteristics of rock material. Test results obtained from uniaxial compressive strength (UCS) are indirectly applicable to the estimation of rock mass behavior since UCS is a main input parameter of Hoek and Brown failure criterion. In this study, samples of sandstone were collected and tested in order to estimate the strength of intact rock. The examined sandstone samples belong to the flysch formation which occupies a large area of western Greece. They usually occupy areas of intense morphological relief and show a dense pattern of discontinuities. Very often they present very well developed bedding, whereas in other cases they are massive.

2. Test procedure

Twenty two block samples were obtained from different outcrops of the flysch formation. Laboratory core drill and saw machines were used to cut the samples and end faces were ground in order to provide cylindrical specimens in size, shape and ends geometries according to testing requirements. The specimen size was 5.4 cm (NX) in diameter with a length to diameter ratio of 2.0 to 2.5. The execution of laboratory tests on intact rock material was in accordance with I.S.R.M. suggested methods (1981, 19865) and A.S.T.M. standards (D 2938-86, D 2845-90). More specifically, the parameters of rock specimens determined by tests carried out in the laboratory, in dry conditions for a better comparison of the results, were as follows: porosity (n), dry density (ρ_d), sound wave velocities (V_p and V_s), point loading index ($I_{s(50)}$), uniaxial compressive strength (UCS-σ_c) and triaxial compression tests for rock material constant m_i determination. The tested samples were also in a fresh state of weathering while the fracture created by strength tests was through the rock material, not following any discontinuity surface, otherwise the test was unacceptable.

3. Test results

The test results are summarized in Table 1, Table 2 and Table 3, including for each parameter the range of values, the mean value and the number of specimens tested. The scattering of data is mainly due to the different degree of diagenesis (compaction or/and cementation) for the various horizons of the sandstone sediments.

Table 1 - Results of intact rock physical parameters

Results and statistical parameters	**n (%)**	**ρ_d (kN/m^3)**
Minimum value (Min)	0.19	23.78
Maximum value (Max)	6.54	26.14
Mean value (Mean)	2.96	25.18
Standard deviation (Std dev)	1.90	0.53
Number of samples (N)	154	154

Table 2 – Results of intact rock dynamic parameters

Results and statistical parameters	**V_p (m/sec)**	**V_s (m/sec)**
Minimum value (Min)	2587.34	1702.86
Maximum value (Max)	5075	3146.71
Mean value (Mean)	4015.22	2624.59
Standard deviation (Std dev)	555.33	289.23
Number of samples (N)	53	53

Table 3 – Results of intact rock strength parameters

Results and statistical parameters	σ_c (MPa)	$I_{s(50)}$ (MPa)
Minimum value (Min)	32.29	1.1
Maximum value (Max)	205.68	7.6
Mean value (Mean)	112.84	4.25
Standard deviation (Std dev)	50.25	1.81
Number of samples (N)	22	36

4. Correlations between intact rock properties

Regression analysis was applied to define the relations among the testing data. The procedure is to fit a line through the points, which is computed so that the squared deviations of the measured points from the line are minimized. The line is defined by the relevant equation, whereas the value of coefficient of determination or R-square value is determined. The number of samples (n) used for regression analyses is also shown.

4.1. Dry density, ρ_d (kN/m^3) and total porosity n (%)

As shown in Figure 1 the trend relating porosity and dry density is an approximately linear function which is expressed by Equation 1. Porosity decreases with increasing dry density. Other authors (Davis 1954, Daly *et al.* 1966, Ramana and Venkatanaryana 1971, Sabatakakis *et al.* 1993, Koukis *et al.* 2001) have also proposed quite similar linear type relationships between these two physical parameters of intact rock for various types of rocks.

Equation 1 - Relationship between dry density and total porosity

$$n = 88 - 3.4\rho_d \qquad (R^2 = 0.90).$$

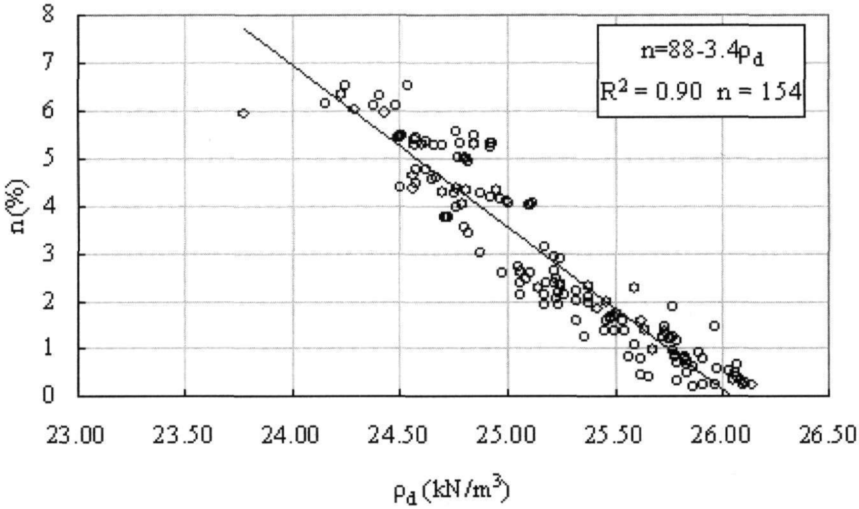

Figure 1 - Correlation between dry density and total porosity

4.2. Sound velocities (V_p, V_s) and porosity (n)

The primary wave velocity values (V_p) range between 2587.34 and 5075 m/sec while the secondary (shear) wave velocities V_s from 1702.86 to 3146.71 m/sec. The relationships show an exponential decrease of sound wave velocities with increasing porosity. The best fitting curves between these parameters is expressed by Equation 2 for V_p and Equation 3 for V_s, while both fitting curves are shown in Figure 2.

Equation 2 - Relationship between velocity of primary waves and porosity

$$V_p = 4469n^{-0.17} \qquad (R^2 = 0.85).$$

Equation 3 – Relationship between velocity of secondary waves and porosity

$$V_s = 2891n^{-0.14} \qquad (R^2 = 0.70).$$

4.3. Uniaxial compressive strength (σ_c) and total porosity (n)

As shown in Figure 3 the values of σ_c seem to decrease as the porosity of rock material increases. A logarithmic fit curve is proposed (Equation 4) although it has a low R-square value (R^2=0.55).

Equation 4 – Relationship between uniaxial compressive strength and porosity

$$\sigma_c = 142 - 38\ln(n) \qquad (R^2 = 0.60)$$

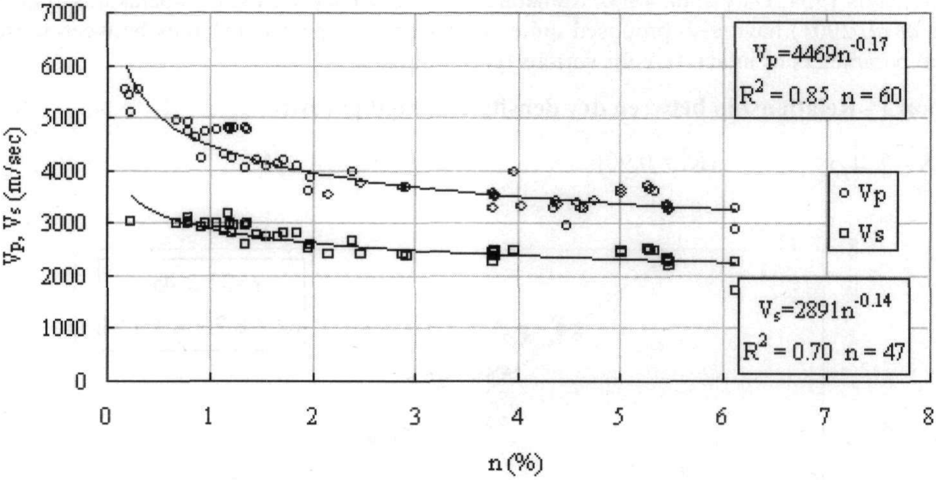

Figure 2 – Correlation between primary and secondary sound wave velocities and porosity

4.4. Uniaxial compressive strength (σ_c) and point load index $I_{s(50)}$ (MPa)

Linear regression models relating the strength values obtained from these tests are the ones commonly reported in the literature (Broch and Franklin 1972, Bieniawski 1974, 1975) that proposed a certain conversion factor for all rock types as function of specimen diameter (24 for NX size). The variation of the origin, composition, texture and diagenesis of the rocks led to conversion factors varying for different types of rock materials (Norbury 1986, Hawkins and Olver 1986, Romana 1999). Finally, different conversion factors have been proposed depending on the rock strength (Hawkins 1998, Romana 1999, Tsiambaos and Sabatakakis 2004).

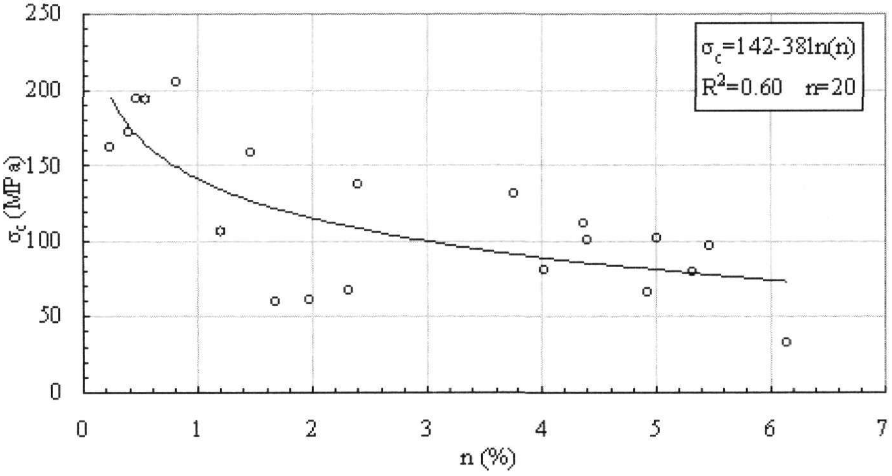

Figure 3 – Correlation between uniaxial compressive strength and porosity

Using additional strength data for sandstones retrieved from the existing Rock Material Properties Data Base, two trends are found relating point load index and UCS values, as shown in Figure 4, an approximately linear and a power function. The equations for the two regression curves are Equation 5 and Equation 6. The linear model for sandstones gives a conversion factor of 23 which is quite similar to that initially proposed by Bieniawski (1974, 1975) and by I.S.R.M. (1981). The power function relationships, seems to fit the data better, exhibiting an R-square value equal to 0.77. The good fit of the power regression, shown in Figure 4 suggests also that there is no single conversion factor applicable to the full range of strength in sandstone rock material. So, relevant conversion factors for specific point load strength ranges that could provide a more realistic determination of uniaxial compressive strength must be estimated (Tsiambaos and Sabatakakis 2004). This approach needs a large number of representative tests on sandstone rock material which are already carried out in the Laboratory of Engineering Geology of Patras University.

Equation 5 – Relationship between uniaxial compressive strength and point load index

$$\sigma_c = 23 I_{s(50)} \quad (R^2 = 0.64).$$

Equation 6 – Relationship between uniaxial compressive strength and point load index

$$\sigma_c = 6.5 I_{s(50)}{}^{1.8} \qquad (R^2 = 0.77).$$

4.5. Triaxial tests

Twenty two triaxial compressive tests were conducted in order to determine the rock material constant m_i. The defined range of $0<\sigma_3<0.5\sigma_{ci}$ (σ_{ci} is uniaxial compressive strength) was used for minor principal stress (σ_3) on intact rock specimens. The m_i value for each set of tested samples (five samples – data points were included in each analysis) has been determined from the fit of the equation describing the Hoek – Brown failure criterion for intact rock to triaxial test data using the Rockdata (1991 – 2001) program. The computed values of m_i as shown in Figure 5 widely ranged from 4 to 40, whereas the interpretation of available values of principal stresses at failure for all sandstones (Fig. 6) give a "mean" value of m_i, about 17 which is quite similar to that proposed by Marinos and Hoek (2000, 2001). Mineral composition analyses of tested samples using microscopic examination have shown that the determined values of material constant m_i are strongly related to the frictional properties of intact rock material and especially to the mineral composition and texture of sandstones. So, the increase of quartzite grains content resulted to decrease of m_i while the increase of calcium carbonate matrix resulted to increase of m_i values.

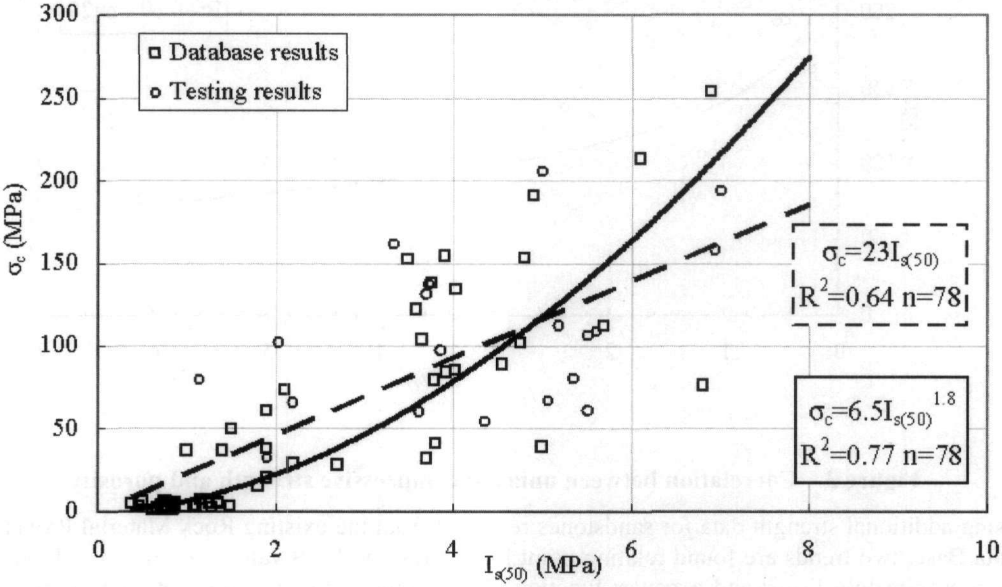

Figure 4 – Correlation between uniaxial compressive strength and point load index

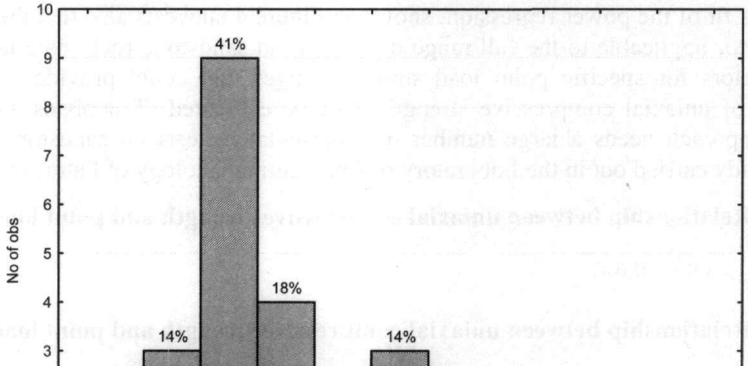

Figure 5 – Histogram of m_i values for sandstone type rock material

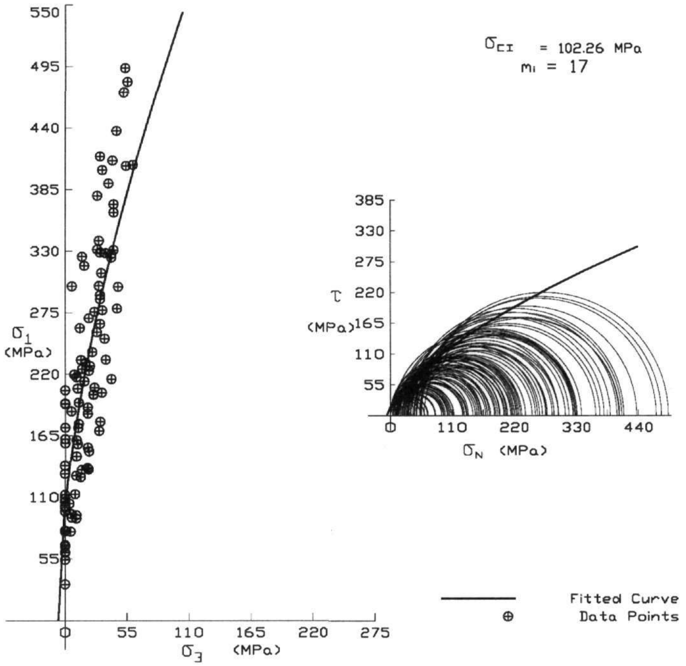

Figure 6 – Intact rock strength envelopes and m_i estimation for sandstones

5. Discussion and conclusions

Sandstones constitute one of the most widely distributed rock type in western Greece. From a series of laboratory test carried out on rock material, the main geotechnical parameters were obtained and interrelationships among them were determined. The relevant equations that describe the correlations between the material parameters are quite similar to those previously proposed by several authors while the observed quantitave differences are mainly due to the variations in origin, composition, texture and diagenesis of the rock material. The correlation between point load and uniaxial compressive strength have also showed that there is not a single conversion factor applicable to full range of strength (soft to hard) in sandstone rock material. Although the computed values of m_i are widely ranged due to mineral composition and structure of sandstones, the "mean" value is quite similar to that reported in the literature. A strong relation have been also observed between the frictional properties of intact rock material as expressed by the mi constant and the mineral composition and texture of sandstones.

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