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CORRELATIONS BETWEEN PHYSICAL PROPERTIES AND POINT LOAD STRENGTH INDEX OF PRASINITES: A CASE STUDY FROM EAST ATTICA PREFECTURE

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Abstract

The aim of this study is to investigate the statistical correlations between the point load strength index and certain physical properties, e.g. the dry density and the dry longitudinal ultrasonic wave velocity of prasinites (metabasites). Statistically significant correlations established between the physical properties as well as between each physical quantity and the point load strength index. According to bibliography, this is one of the first efforts to develop relations between physical and mechanical properties for this particular petrological type, and therefore the derived equations can be a useful tool to the investigation of these petrological types, either in the study area or in other sites, where prasinites of similar structural characteristics, are examined for the foundation of various constructions.
Keywords: *Density, Ultrasonic wave velocity, Mechanical properties, Statistical relationships, Metabasites.*

Περίληψη

Ο σκοπός της παρούσας εργασίας είναι η διερεύνηση των στατιστικών συσχετίσεων μεταξύ του δείκτη αντοχής σημειακής φόρτισης και συγκεκριμένων φυσικών ιδιοτήτων, όπως της πυκνότητας και της ταχύτητας των διαμήκων υπερηχητικών κυμάτων σε ξηρή κατάσταση, για την περίπτωση των πρασινιτών (μεταβασίτες). Επιβεβαιώθηκαν, στατιστικά, σημαντικές συσχετίσεις μεταξύ των φυσικών ιδιοτήτων καθώς και μεταξύ εκάστης φυσικής ιδιότητας και του δείκτη αντοχής σημειακής φόρτισης. Σύμφωνα με την βιβλιογραφία, η εργασία αυτή αποτελεί μια πρώτη προσπάθεια ανάδειξης τέτοιων συσχετίσεων για τον συγκεκριμένο πετρολογικό τύπο, με αποτέλεσμα, οι εξισώσεις που προέκυψαν να αποτελούν χρήσιμο εργαλείο στην μελέτη αυτών των πετρολογικών τύπων τόσο στην περιοχή έρευνας, όσο και σε άλλες περιοχές όπου οι πρασινίτες, με παρόμοια δομικά χαρακτηριστικά, αποτελούν αντικείμενο μελέτης για τη θεμελίωση κατασκευών.
Λέξεις κλειδιά: *Πυκνότητα, Ταχύτητα διάδοσης υπερήχων, Μηχανικές ιδιότητες, Στατιστικές συσχετίσεις, Μεταβασίτες.*

1. Introduction

Since the fundamental work of (Broch and Franklin, 1972) and (Guidicini *et al.*, 1973), the point load test obtained considerable attention in the geotechnical practice, due to its simplicity and inexpensive use. The point load strength index (Is) can be used for strength classification of the intact rock (Bieniawski, 1975), as well as an input parameter in the RMR classification system (Bieniawski, 1989). Despite the tensile nature of the test, several researchers have investigated the relationship between the point load strength index and unconfined compressive strength. In the study of Fener *et al.* (2005), the interested reader can find and assess numerous empirical equations for a variety of rock types.

It is a common and at the same time challenging task in the geotechnical engineering, trying to establish empirical correlations between measures of rock strength and intrinsic properties which control the strength of the intact rock. A number of researchers, (e.g., Irfan and Dearman, 1978, Pasamehmetoglu *et al.*, 1981; Beavis, 1985; Rozos, 1989; Augustinus, 1991; Gupta and Seshagiri Rao, 1998; Palchik and Hatzor, 2004; Shafiei *et al.*, 2007; Kurtulus *et al.*, 2012; Altindag, 2012) have investigated the relationship among some physical property like the absolute or effective porosity, the specific gravity and the longitudinal ultrasonic wave velocity with the point load strength index. In the aforementioned studies, irrespectively of the mathematical formulation e.g. linear, exponential or power, the common trend is the reduction of the point load strength index as the porosity increases and the increase of the index as the density or the wave velocity increases.

The objective of this study is to derive new correlation equations between the dry density and dry longitudinal ultrasonic wave velocity with the size corrected point load strength index $Is_{(50)}$, obtained from axial point load tests, in the case of prasinites. For this reason, a total of fourteen (14) rock samples were collected from the area of East Attica Prefecture and sixty-eight (68) rock disks prepared and tested. The results were analyzed using ordinary least squares regression and the derived equations proved to be statistically significant with strong coefficients of determination.

2. Location and Geological Aspects of the Study Area

The geographical distribution of the collected rock samples is shown in Figure 1. The study area is located in the south part of the East Attica Prefecture and extends from north to south between the sites of Ano Daskalio village and Sounio town. The bodies of prasinites (metabasites) belongs to the so called Neo - Hellenic Nappe (Katsikatsos, 1992), as intercalations within the formations of phyllites, schists and quartzites. Their maximum thickness can reach up to 50 m. They are poorly foliated and can be categorized either as bluschists or greenschists with the later to be the predominant rock type (Baziotis *et al.*, 2008).

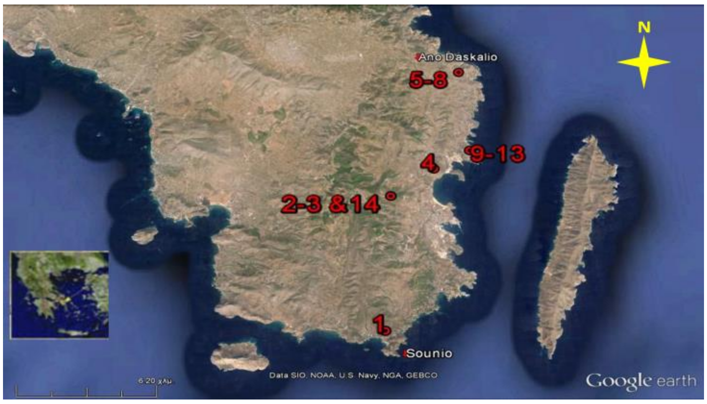

Figure 1 - Location of samples (Numbers refers to rock codes).

In the field, prasinites appeared as massive relatively fresh formations, in cases with a dense net of calcite veins and at some places intensively fractured and weathered due to the presence of the soluble calcite veins. (Fig. 2).

Figure 2 - (a) Intensively fractured and weathered prasinites, (b) Fresh prasinites.

3. Experimental Procedure and Results

The fourteen (14) rock blocks collected, helped to produce a total number of sixty-eight (68) right circular disks of NX diameter. These disks were prepared in accordance with the suggested methods of ISRM (ISRM, 1981a). The collection of specimens was performed in such a way, to capture, as much as possible, the whole spectrum of the weathering characteristics of the formation (Fig. 3), in order to result in statistically significant correlations. Samples with distinct features of foliation were excluded from the statistical analysis in order to avoid the influence of anisotropy to the wave propagation.

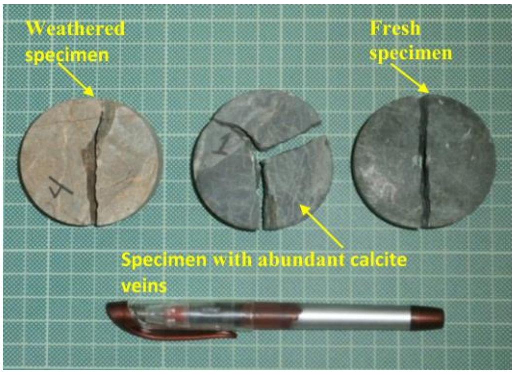

Figure 3 - Prasinites with various stages of weathering.

3.1. Dry Density

The dry density was measured after the oven - drying of the specimens at 40°C for several days until to get a constant mass. In spite of the suggested methods of ISRM (ISRM, 1981a), for the determination of the dry density, the temperature was set at this level, in order to avoid any thermal degradation due to the presence of calcite in the mineralogical composition. After the oven-drying the specimens were placed in a desiccator for two days to reach up temperature equilibrium.

The values of dry density range between 2.565 gr/cm^3 and 2.983 gr/cm^3 and the inherent variability of the selected samples is shown as box plots in Figure 4.

According to IAEG classification (Table 1 - Anon, 1979), the prasinites in the study area are classified as formations of high up to very high dry density.

Table 1 - Dry density classes for hard and soft rocks (Anon, 1079).

Class	Range (gr/cm^3)	Term
1	< 1.80	Very Low
2	1.80-2.20	Low
3	2.20-2.55	Moderate
4	2.55-2.75	High
5	> 2.75	Very High

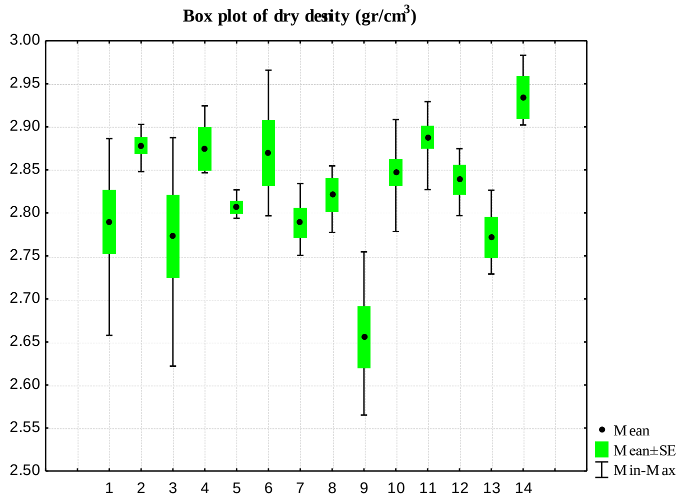

Figure 4 - Box plot of dry density of examined samples.

3.2. Dry Longitudinal Ultrasonic Wave Velocity

This property is very sensitive to various structural characteristics of a rock, like the mineralogical composition, grain size, porosity, joints, cracks and anisotropy. In the ultrasonic pulse method, the wave speed is calculated by dividing the distance between the transmitter and the receiver by the time required for the transient pulse to travel this distance. In the present study a Pundit testing instrument was used, equipped with transducers of 150 kHz dominant frequency. The configuration of direct transmission was used and further details of the experimental procedure were in line with the upgraded suggestions of ISRM. (Aydin, 2015).

The dry longitudinal ultrasonic wave velocity ranges from 3.947 km/s up to 6.540 km/s (Fig. 5). This variation is attributed to the various states of weathering and also to the presence of a dense net of calcite veins in a number of rock samples.

According to IAEG classification (Table 2 - Anon, 1979), the prasinites in the study area are classified as formations of moderate up to very high dry longitudinal ultrasonic wave velocity.

Table 2 - Dry longitudinal ultrasonic wave velocity classes for hard and soft rocks (Anon, 1979).

Class	Range (km/s)	Term
1	< 2.5	Very Low
2	2.5-3.5	Low
3	3.5-4.0	Moderate
4	4.0-5.0	High
5	> 5.0	Very High

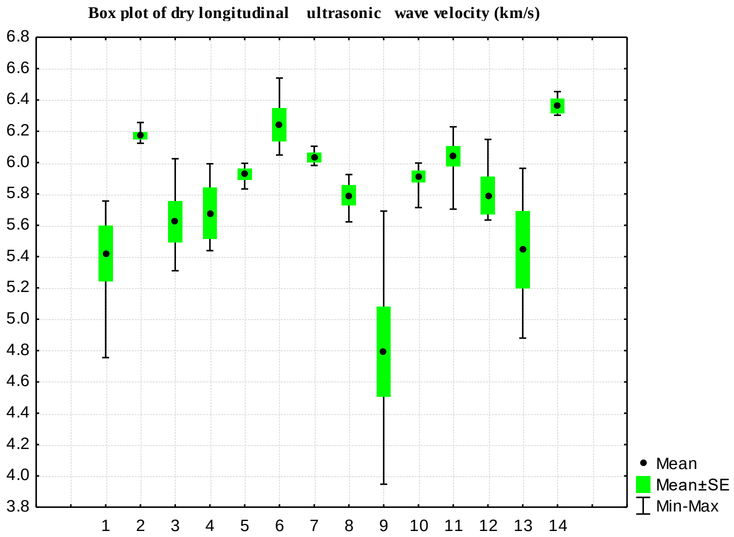

Figure 5 - Box plot of dry longitudinal ultrasonic wave velocity of examined samples.

3.3. Point Load Strength Index $Is_{(50)}$

After the determination of the physical and acoustical properties the specimens were tested in a portable machine of 50kN load capacity in order to obtain the axial point load strength index Is and hence the corrected one $Is_{(50)}$. The experimental procedure and the relevant calculations were in accordance with the suggested methods of ISRM (ISRM, 1985b).

The corrected point load strength index $Is_{(50)}$ shows a wide scatter, as shown in Figure 6, with values between 1.64 MPa and 13.71 MPa, characterising the material's strength, according to the classification of Bieniawski (Table 3 - Bieniawski, 1975) as low up to very high.

Table 3 - Rock materials classification according to PLS index (Bieniawski, 1975).

Description	Point load strength index (MPa)
Very high strength	>8
high strength	4-8
Medium strength	2-4
Low strength	1-2
Very low strength	<1

The coefficient of variation, a dimensionless measure of variability in the test results (CoV %) range between 3.52% up to 35.45% and is thought to be adequate for practical geotechnical applications (Kahraman and Gunaydin, 2009).

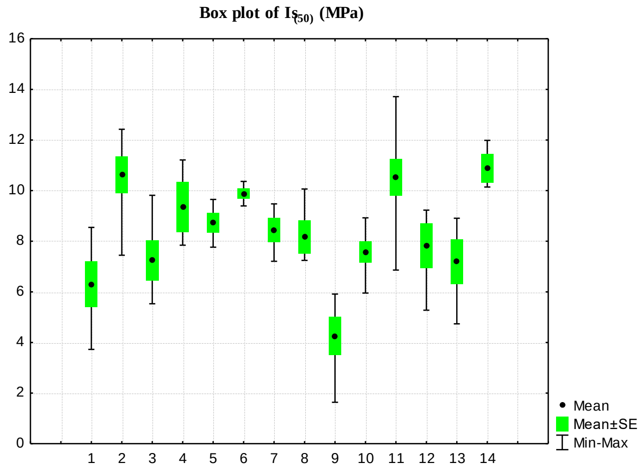

Figure 6 - Box plot of $Is_{(50)}$ of examined samples.

4. Statistical Analysis

The descriptive statistics, e.g. the mean, the standard deviation (SD) and the coefficient of variation (CoV) of the physical and mechanical properties for each one of the fourteen (14) selected samples are summarized in Table 4.

Table 4 - Descriptive statistics of the physical and mechanical properties.

code	Dry Density		Dry Lon. Ult. Wave Vel.		$Is_{(50)}$	
	Mean ± SD (gr/cm3)	CoV (%)	Mean ± SD (km/s)	CoV (%)	Mean ± SD (MPa)	CoV (%)
1	2.790 ± 0.074	2.67	5.420 ± 0.353	6.52	6.30 ± 1.79	28.46
2	2.878 ± 0.022	0.75	6.171 ± 0.047	0.76	10.63 ± 1.62	15.28
3	2.773 ± 0.096	3.45	5.623 ± 0.261	4.65	7.24 ± 1.57	21.67
4	2.875 ± 0.035	1.23	5.677 ± 0.233	4.10	9.35 ± 1.40	14.97
5	2.807 ± 0.013	0.46	5.925 ± 0.061	1.04	8.74 ± 0.67	7.66
6	2.870 ± 0.066	2.29	6.242 ± 0.182	2.92	9.88 ± 0.35	3.52
7	2.789 ± 0.030	1.07	6.032 ± 0.052	0.85	8.44 ± 0.82	9.69
8	2.821 ± 0.034	1.20	5.791 ± 0.111	1.92	8.17 ± 1.13	13.84
9	2.655 ± 0.072	2.70	4.793 ± 0.576	12.02	4.26 ± 1.51	35.45
10	2.847 ± 0.044	1.56	5.911 ± 0.029	0.49	7.58 ± 1.15	15.14
11	2.888 ± 0.039	1.34	6.040 ± 0.191	3.16	10.53 ± 2.15	20.45
12	2.839 ± 0.030	1.04	5.790 ± 0.210	3.62	7.82 ± 1.51	19.37
13	2.731 ± 0.041	1.48	5.444 ± 0.427	7.84	7.19 ± 1.52	21.15
14	2.934 ± 0.035	1.20	6.362 ± 0.066	1.03	10.89 ± 0.79	7.30

The mean values of the above results were analyzed using the method of ordinary least squares regression, implemented in Matlab 12. The equation of the best fit along with the ±95% prediction bounds of the function and the coefficient of determination (R^2) were determined for each one of the three models, e.g. the dry longitudinal wave velocity versus the dry density, the point load strength index versus the dry density, and finally the point load strength index versus the dry longitudinal wave velocity.

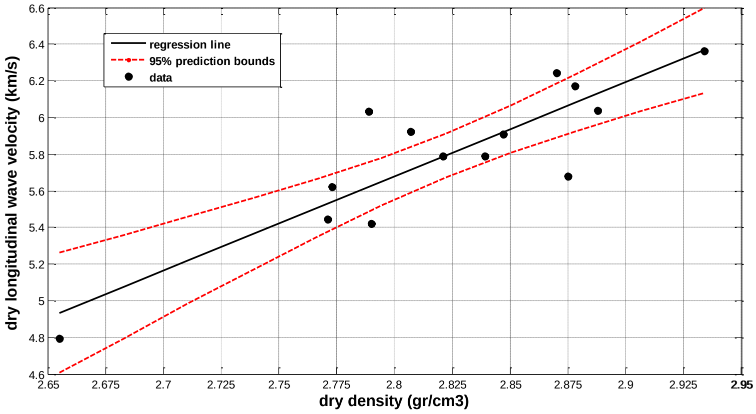

Figure 7 - Dry longitudinal wave velocity versus dry density.

The relationship between the dry density ρ_d (in gr/cm^3) and the dry longitudinal wave velocity v_l (in km/s) was found to be linear (Fig. 7). Density is thought to be the principal factor affecting the velocity of longitudinal waves and in general their correlation is of a linear form (Lama and Vutukuri, 1978).

The equation of the line is:

$$v_l = 5.135 * \rho_d - 8.701 \qquad R^2 = 0.76 \qquad (1)$$

The ±95% prediction bounds for the slope and the intercept are (3.329, 6.942) and (-13.8, -3.598) respectively.

The point load strength index (in dry conditions) $Is_{(50)}$, (in MPa), exhibits a linear increase with the increase in dry density (Fig. 8).

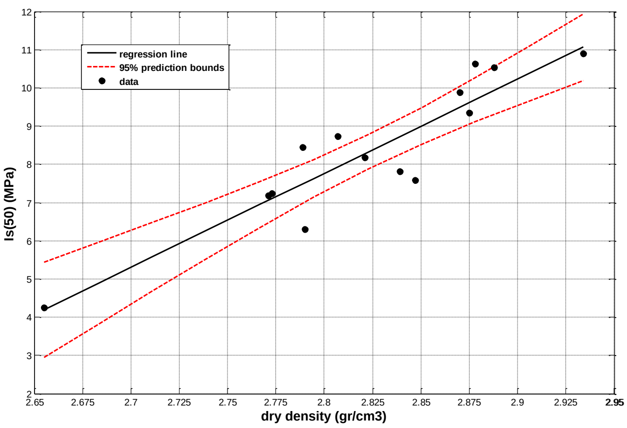

Figure 8 - $Is_{(50)}$ versus dry density.

The equation of the line is:

$$Is_{(50)} = 24.62 * \rho_d - 61.17 \qquad R^2 = 0.84 \qquad (2)$$

The ±95% prediction bounds for the slope and the intercept are (17.8, 31.44) and (-80.44, -41.9) respectively.

In the same manner, the point load strength index $Is_{(50)}$, shows a linear increase with the increase in dry longitudinal wave velocity (Fig. 9).

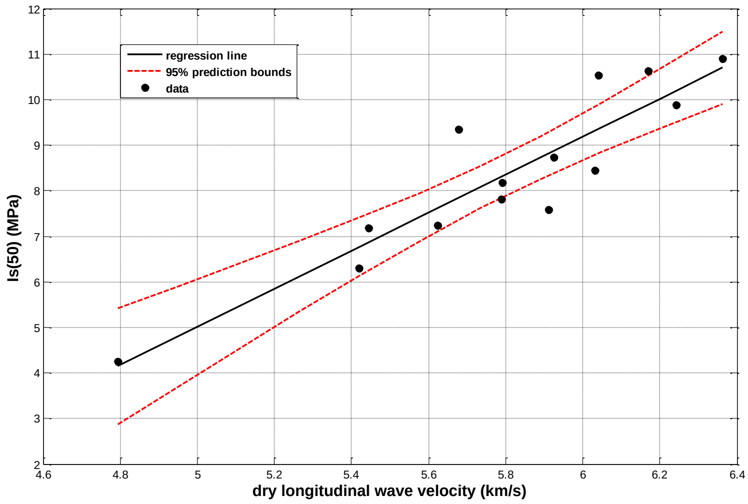

Figure 9 - $Is_{(50)}$ versus dry longitudinal wave velocity.

In this case the equation of the line is:

$$Is_{(50)} = 4.173 * v_l - 15.85 \qquad R^2 = 0.83 \qquad (3)$$

The ±95% prediction bounds for the slope and the intercept are (2.999, 5.348) and (-22.68, -9.025) respectively.

5. Statistical Significance of The Results

The significance of the regression coefficients was determined via the t-test. This test examines if the null hypothesis, which states that the regression coefficient is zero, is truth. If the computed t-values are greater than the tabulated t-values, the null hypothesis is rejected. For 95% confidence level, the critical t-value for the derived models is ±2.18. The calculated t-values are summarized in Table 5. As seen the computed t-values are greater than the tabulated ones, so the linear correlations between the variables are real.

Table 5 - Significance of the coefficients.

Equation No.	t-computed	t-critical
1	6.19	±2.18
2	7.88	±2.18
3	7.74	±2.18

6. Conclusions

Laboratory tests were carried out for the determination of the dry density, the dry longitudinal wave velocity and the axial point load strength index for the petrological type of prasinites (metabasites). A linear relationship between the physical properties was established. The point load strength index was found to increase linearly with the increase in both of the physical properties.

The correlations exhibits strong coefficients of determination and proved to be statistically significant. The above equations can be used from the geoscientists, who deal with geotechnical problems occupied in the study area, but also in the case of other areas, where prasinites with similar structural characteristics, outcrop.

7. Acknowledgments

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