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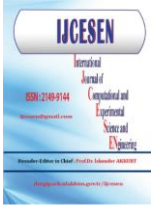

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Research Article

Engineering Properties of Eğirdir-Kızıldağ Harzburgitic Peridotites in Southwestern Turkey

Züheyr KAMACI[1]*, Pelin ÖZER[2]

[1]Süleyman Demirel Üniversity, Faculty of Engineering, Geophysics Department, 32200, Isparta-Turkey
[2]Süleyman Demirel Üniversity, Graduate School of Applied and Naturel Sciences, Geophysics Dep., Isparta-Turkey

* Corresponding Author : zuheyrkamaci@sdu.edu.tr
ORCID: 0000-0002-2331-0162

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Abstract: In rock mechanics, various methods are available to detect the rock properties. The aim of this study is to determine physical and mechanical properties of the serpentinized ultrabasic rocks such as Eğirdir-Kızıldağ Harzburgitic Peridotites. The serpentinized ultrabasic rocks are commonly used for architecture and the ground under road bases in many areas and also widely used for indoor elements such as tables, pilasters and ornaments of different kinds. In this study, geophysical and geotechnical tests including P and S- wave velocities, rigidity modulus, Poisson ratio, elasticity modulus, bulk modulus, natural period, safe bearing capacity and bedding coefficient were performed on nine rock samples, collected from different areas. Geophysical and geotechnical studies were carried out both parallel and perpendicular to foliation planes of the cubic samples. Ultrasonic P-Wave Velocity (UPV), Uniaxial Compressive Strength (UCS), volumetric water contents, effective porosity, unit volume weight, density and weight of all samples were calculated. Finally, statistical relations among the measured parameters were established by using regression analysis.

1. Introduction

Geologically, rocks are divided into three classes such as magmatic, metamorphic and sedimentary rocks. However, rock classifications used in engineering studies are very different to geological classifications, because for engineering studies durability and sensitivity gain importance rather than the source of the rocks. Rocks classified as basic and ultrabasic have gained significant value in the natural rock sector in recent years. As a result with demand reaching significant levels, in addition to the sectoral name of magmatic rocks, some terms related to mineralogy and petrography have entered the natural stone sector. Some rock properties were determined and defining the correlations between them, provides significant benefits especially in terms of feasibility for engineering and interior-exterior decorative work.

As explained in the related standards for determine uniaxial compressive strength of rocks (UCS) which is important for engineering classification of rocks, smooth-cut cube-shaped rock samples are required. Though many studies like [1-16] have been completed to determine the mechanical and engineering properties of rocks with the UCS test, these studies were only completed on ultrabasic rocks with very little serpentinization [17-27]. In this research the engineering and mechanical properties of serpentinized ultrabasic rocks called the “Eğirdir Kızıldağ Harzburgite” [28] outcropping south of Isparta-Pazarköy in southwest Turkey were determined with geological and geophysical methods.

In addition to geophysical studies like seismic refraction, electrical resistivity and micro tremor, cubic samples obtained from rock blocks in the field had uniaxial compressive strength (UCS), ultrasonic seismic velocity (UPV), saturated and dry volume weight, volume and weight water absorption, density and porosity experiments performed both perpendicular and parallel to foliation. The data obtained from the experiments were statistically analyzed with a simple regression method and interpreted.

2. Geology of The Investigation Area

The study [29] was focused on the mafic-ultramafic rocks on the north wing of the Antalya complex in Southwest Turkey in terms of geological, chemical and geodynamic properties (Fig. 1).

The oldest unit in the area covered by the study is the Anamas-Akseki Platform which is basically comprised of limestone and dolomites. The sequence from bottom to top is as follows. The oldest unit of the platform is upper Manian-Rhaetian Menteşe dolomites. At the top the Menteşe dolomites pass up into upper Lias-Upper Cretaceous Alakilise limestones. Above these limestones the dominant lithologies are micritic limestone, occasional shale and claystones. Then there are the Upper Cretaceous Eşekini limestones [30]. The Anamas-Akseki platform comprises Campanian-Maastrictian age limestones and ends with the Anamasdağ limestones [31]. Above these are sedimentary rock units of the Pazarköy Group reflecting different basin conditions brought together by tectonic relations and again volcanic rocks from different tectonic environments (Akpınar Tepe volcanics, Havutlu volcanics) and Kızıldağ peridotites, Dulup limestones, and Öbektaş formation tectonically emplaced (Fig. 1).

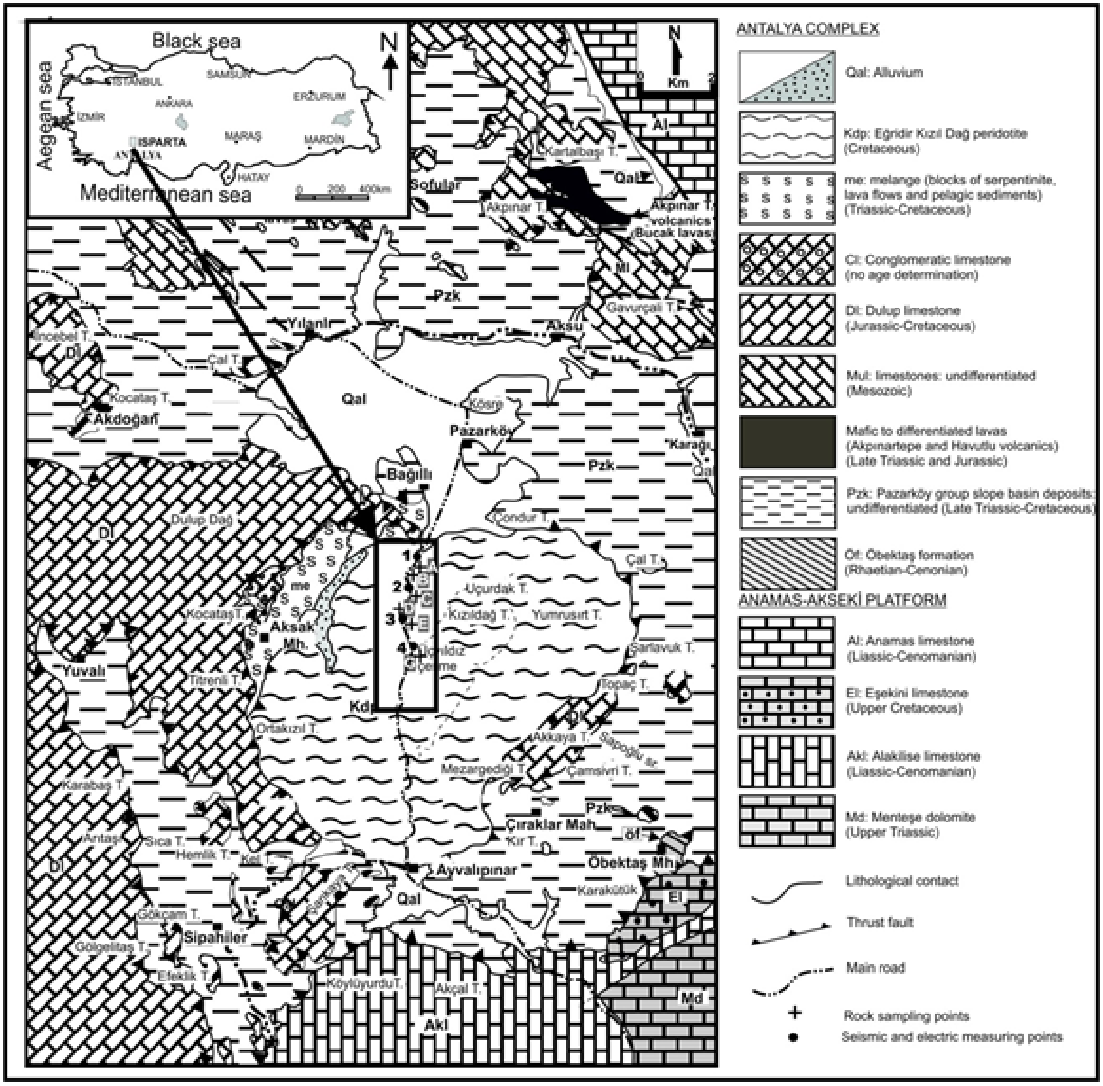


***Figure 1.** Location and geological map of the study area (modified from [29])*

Kızıldağ Peridotites are mainly harzburgitic peridotites with pyroxenite and isolated diabase dykes cutting them and occasional lens-shaped dunites within the harzburgites. The peridotites generally have weathered surfaces of brown, yellowish-brown and greenish-brown, with fresh broken surfaces dark green, black-green, and yellowish-green color tones (Fig. 2).

These harzburgites contain magmatic foliation and there are pyroxene minerals or pyroxene-rich thin layers parallel to this banding [29]. The mineralogical composition of these rocks, and the scarcity or abundance of the minerals, is very important in terms of naming the rocks, the cutting and polishing of the rocks, trade value and even block production. When mineralogical properties of rock samples used in experiments is examined, in places with magmatic foliation observed mineralogical and petrography properties were investigated in thin sections obtained with two orientations, perpendicular and parallel to the foliation (Fig. 3).

Figure 2. *Serpentinized ultrabasic rocks exposed in SW Turkey (Isparta-Eğirdir-Pazarköy).*

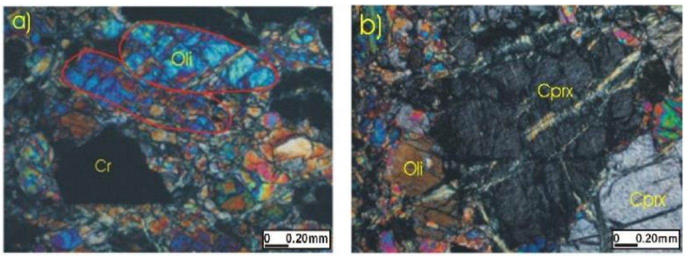


Figure 3. *Section view of the harzburgite forming minerals (Olivine, Clinopyroxene and Cromite)***,** *a) along foliation, b) across foliation.*

The basic minerals in the rock are olivine and clinopyroxenes. Accessory minerals include chromite. The majority of holocrystalline texture in the rock is comprised of olivine. Olivines with anhedral and semi-euhedral crystals are altered and serpentinized at the edges and on cleavage planes. As a result olivines display sieve texture. Crystals are medium-large size. Clinopyroxene minerals are represented by enstatite. These are generally large crystals with some medium size. Like olivines these appear serpentinized. Additionally polysynthetic twinning is present. The most important difference between sections perpendicular to foliation and those parallel to foliation is in the shape of the minerals. In sections perpendicular to foliation, minerals are generally have round or ellipsoid shape, while in sections parallel to foliation they are lengthened in a particular direction. Medium grain size chromites are semi-euhedral and anhedral and opaque. Fig.3 shows oli: olivine, cprx: clinopyroxenes and cr: chromite.

3. Material and Methods

This study was conducted covering the South of Isparta-Eğirdir-Pazarköy was completed in two stages as field and laboratory studies.

3.1 Field Studies

In the field, geophysical seismic refraction, microtremor and electrical resistivity studies were completed at five different points (Fig. 1). Seismic refraction and electrical resistivity studies were used to obtained the dynamic properties of serpentinized ultrabasic rocks. Seismic refraction data was recorded on a 12 channel WZG-48 model seismograph. The P and S seismic velocities of the layers were calculated using the Esos-Seisimager evaluation program. Using the experimental equations found in studies [32-33], [25] and [34], the elasticity modulus of rocks was determined using P and S seismic velocities values. The mean calculated P and S wave velocities were given in Table 1.

Here P and S seismic wave velocities are V_P and V_S , the dry unit weight is DUW, Poisson's ratio is υ, the rigidity modulus is G, the elasticity modulus is E, the bulk modulus is k, the safety bearing capacity is q_S, the bearing coefficient is K_S and The natural period is T_o . The natural period of the ground at the points where seismic measurements were taken was measured with a CMG-6TD Broad-Band microtremor instrument. At each point a 30 minute measurement duration used with 100 Hz sampling interval with measurements taken in a 25 second window with 5% overlap with mean values taken from the obtained results.

Electric resistivity data was obtained with a Schlumberger electrode array Vertical Electrical Sounding (VES) technique (Fig. 1). Mean 60 meters was chosen as the current electrode interval (AB). VES curves were assessed and interpreted with the IP2WIN computer iteration technique.

3.2 Laboratory Studies

According to [35] and [36] standards, uniaxial compressive strength experiments were completed on 2 x 2 x 2 inch, or 51 x 51 x 51 mm, cubic rock samples.

3.2.1 Ultrasonic Pulse Velocity Measurements (UPV)

Ultrasonic pulse velocity (UPV) tests were conducted using Pundit Plus tester consist of placing two piezoelectric transducers on two opposite sides of the samples and the travel time which is through the exact distance between the transducers was measured. UPV test was conducted on cubic samples of 51x51x51 mm. The surface of the cubic specimens was polished and used stiffer grease for good coupling. Experiments were initially conducted on dry samples. The same experiments were then repeated after samples were saturated with water and were given in Table 2. The test results of studies by [37], [12] and [25] showed that seismic velocity values parallel to foliation were always higher than those perpendiculars to foliation and this situation is due to the anisotropic properties of the rock. Based on this, the P-wave velocities (Vp) of cubic rock samples in this study were separately determined according to [38] standards , with a PUNDIT7-UPV E48 brand seismic velocity instruments and same results were obtained from the experiments.

3.3 Geotechnical Studies

Cubic samples obtained from four different locations were made with polished surfaces. A total of 6 different groups of samples were obtained from the same location and numbered accordingly (A1- B1- B2- B3- C1- D1- E1- E2- G1) for a total of 66 rock samples. Physical properties such as density, unit volume weight, effective porosity, mass and volume water absorption rates and seismic velocity were determined. Density experiments were completed according to standard [39], 3 times on each sample and arithmetic mean of assessments were taken.

Some physical properties of rocks such as dry unit volume weight, water absorption capacity (by volume and by weight), effective and total porosity were determined all this properties of rocks which were performed in dry conditions were determined using saturation and buoyancy techniques according to related standarts such as recommended by [36], [40] and [38].

3.3.1 Uniaxial Compressive Strength Experiment (UCS)

The uniaxial compressive strength (UCS) of the specimens was determined according to related standard [38] and by subjecting each specimen to incremental loading at a nearly constant rate with the 200 ton loading capacity hydraulic press [41].

4. Results and Discussion

All physical and mechanical properties of serpentinized ultrabasic rock samples were given in Table 2. To determine a range of correlations between these results, the least squares regression analysis method was used. to This regression analysis was carried out to determine correlations between UCS and Wn, UCS and n, UCS and DUW, UCS and γ_S , Wn and Vp, n and Vp, DUW and Vp, γ_S and Vp and UCS and Vp perpendicular and parallel to foliation and degrees of fit are shown with the graphs (Fig. 4-12).

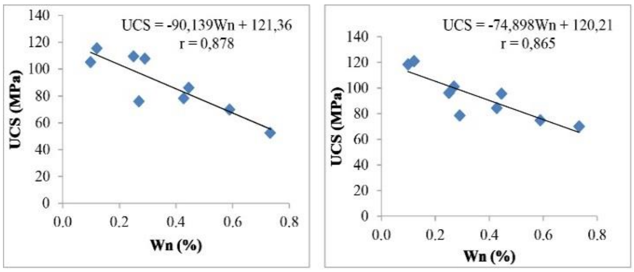


Figure 4. *Scatter plot of UCS against Water apsorption (Wn) for cubic specimens with respect to a) across foliation, b) along foliation.*

All correlations between the engineering properties of rocks according to UCS and Vp were given together in Table 3. Accordingly the highest correlation coefficient (**r**) was 0.95 found between DUW and V_P of samples perpendicular to foliation. For samples parallel to foliation the correlation coefficients for Wn and V_P and n and V_P were about 0.94. The lowest correlation coefficient for perpendicular samples was 0.80 for DUW and UCS and 0.78 for γ_S and UCS. Similary there there was a good negative linear correlation for UCS and Wn and UCS and n perpendicular and parallel to foliation (Fig. 4-5). Accordingly as Wn or n values increase in these rock samples, the UCS value decreased. There was a positive linear correlation between UCS and DUW and UCS and γ_S perpendicular and parallel to foliation (Fig. 6-7). As DUW or density (γ_S) increase in rock samples, the UCS value increases. There was adverse linear correlation between V_P and Wn and V_P and n perpendicular and parallel to foliation (Fig. 8-9). Here as Wn and n increase, the V_P seismic velocity value decreases. When the n value is equivalent to effective porosity, it can be said there is a linear correlation between porosity and seismic velocity. There is a positive linear correlation between V_P and DUW and V_P and density (γ_S) perpendicular and parallel to foliation (Fig. 10-11). As the density and unit volume weight (DUW) increase, the seismic velocity value increases.

As shown in Fig. 12, there is a positive linear correlation between UCS and V_P. In other words as seismic velocity increases, the UCS value increases. As a result, very significant relations was determined between UPV (=V_P) and mechanical and engineering properties of the serpentinized ultrabasic rocks.

5. Conclusions

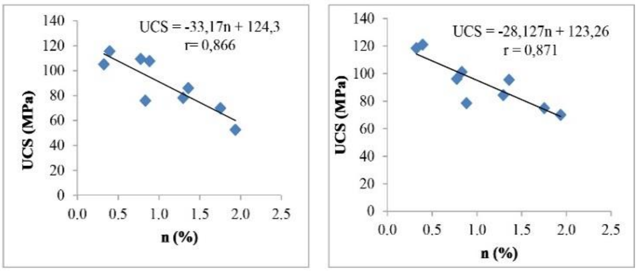
The most important purpose of this work was to figure out the physical and mechanical properties of rocks, as well as dynamic engineering properties, of serpentinized ultrabasic rocks.

Table 1: *Average dynamic P- and S- wave velocities and engineering properties of serpentinized ultrabasic rocks determined from seismic refraction survey in the investigation area.*

Seismic Locations	Vp [m/s]	Vs [m/s]	DUW [kN/m3] $DUW = (0.002 * V_p) + 16$	υ $\upsilon = \frac{V_p^2 - 2 * V_s^2}{2 * (V_p^2 - V_s^2)}$	G [Gpa] $G = \frac{DUW * V_s^2}{100}$	E [Gpa] $E = 2 * (1 + \upsilon) * G$	K [kN/m3] $k = \frac{2 * (1 + \upsilon)}{3 * (1 - 2 * \upsilon)} * G$	To [s]	qs [kPa] $q_s = 0.024 * DUW * V_s$	Ks [kN/m3] $K_s = 40 * \frac{V_p}{V_s} * q_s * 19.99$
1	4701	2582	25,40	0,28	16,93	42,34	32,90E+08	0,09	1573,98	2291427
2	4317	2213	24,63	0,32	12,06	31,83	29,42E+08		1308,14	2040458
3	4590	2489	25,18	0,29	15,59	40,22	31,62E+08		1504,15	2217950
4	5549	2828	27,10	0,32	21,67	57,21	53,47E+08		1839,33	2885810
Average Standard deviation	346,38	185,89	0,70	0,02	2,63	6,68	3,11	-	149,45	232914,7

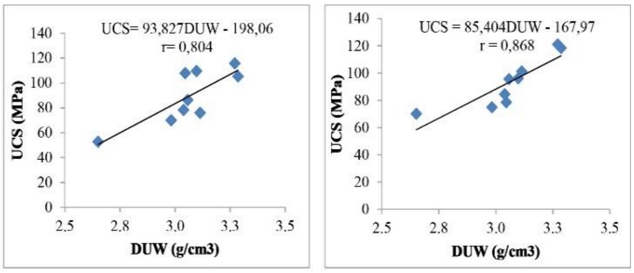
Table 2*: Summary of results of dry and saturated unit weight, water absorption and effective porosity, wave velocity, and uniaxial compressive strength (UCS) with respect to orientation of foliation.*

Sample No	Water absorption W_n [%]	Effective porosity n [%]	Dry Unit Weight DUW [g/cm^3]	Saturated unit weight, γs [g/cm^3]	Total porosity Pt [%]	Across Foliation		Along Foliation	
						Vp [m/s]	UCS [MPa]	Vp [m/s]	UCS [MPa]
A1	0,59	1,75	2,98	3,15	0,05	5564	69,99	6063	74,93
B1	0,43	1,30	3,04	3,15	0,04	5907	78,34	6433	84,41
B2	0,27	0,83	3,11	3,25	0,04	5913	76,03	7853	101,21
B3	0,45	1,36	3,06	3,18	0,04	5683	86,24	6605	95,56
C1	0,73	1,94	2,65	2,69	0,01	4416	52,64	5723	70,04
D1	0,29	0,88	3,05	3,19	0,04	5933	107,88	6852	78,61
E1	0,10	0,33	3,29	3,35	0,02	7429	105,30	8009	118,42
E2	0,12	0,40	3,27	3,41	0,04	7435	115,64	7923	121,05
G1	0,25	0,78	3,10	3,21	0,03	6473	109,52	7024	96,18
Average Standart Devition	0,21	0,56	0,19	0,20	0,01	941	21,58	835	27,27



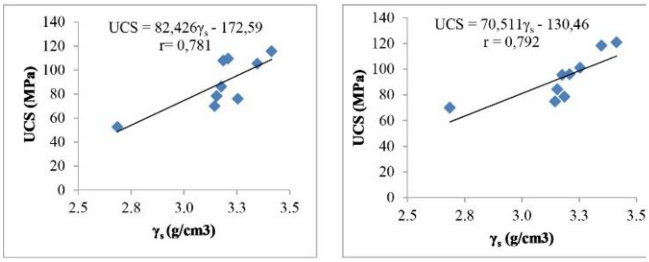
a **b**

Figure 5. *Scatter plot of UCS against Effective porosity (n) for cubic specimens with respect to a) across foliation, b) along foliation.*



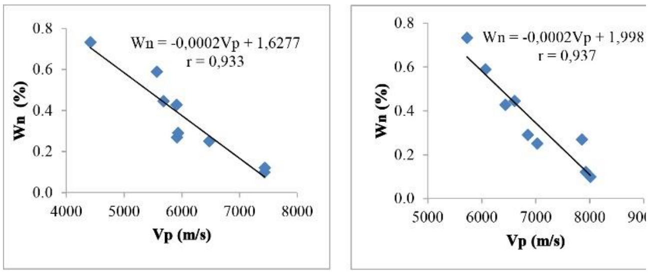
a **b**

Figure 6. *Scatter plot of UCS against Dry Unit Weight (DUW) for cubic specimens with respect to a) across foliation, b) along foliation.*



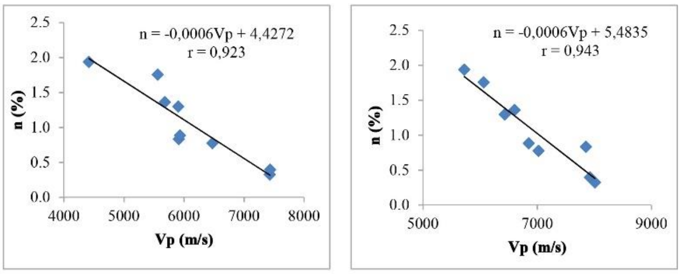
a **b**

Figure 7. *Scatter plot of UCS against Saturated unit weight (γ_s) for cubic specimens with respect to a) across foliation, b) along foliation.*



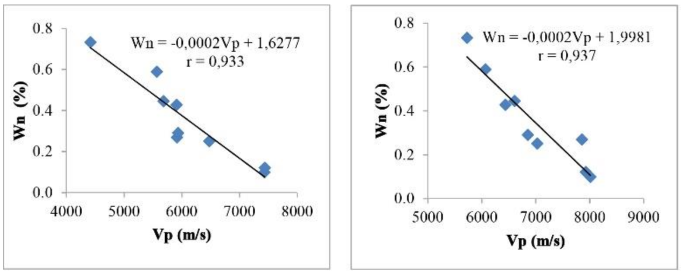
a **b**

Figure 8. *Scatter plot of Water absorption (Wn) against Vp for cubic specimens with respect to a) across foliation, b) along foliation.*



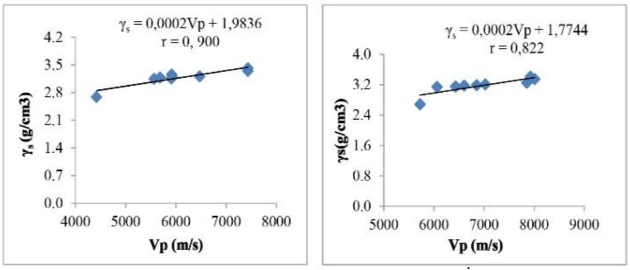
a **b**

Figure 9. *Scatter plot of Effective porosity (n) against Vp for cubic specimens with respect to a) across foliation, b) along foliation.*



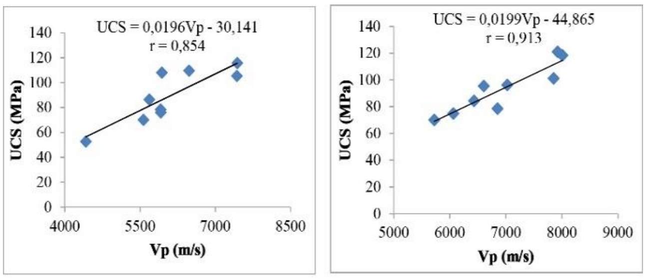
a **b**

Figure 10. *Scatter plot of Dry Unit Weight (DUW) against Vp for cubic specimens with respect to a) across foliation, b) along foliation.*



a **b**

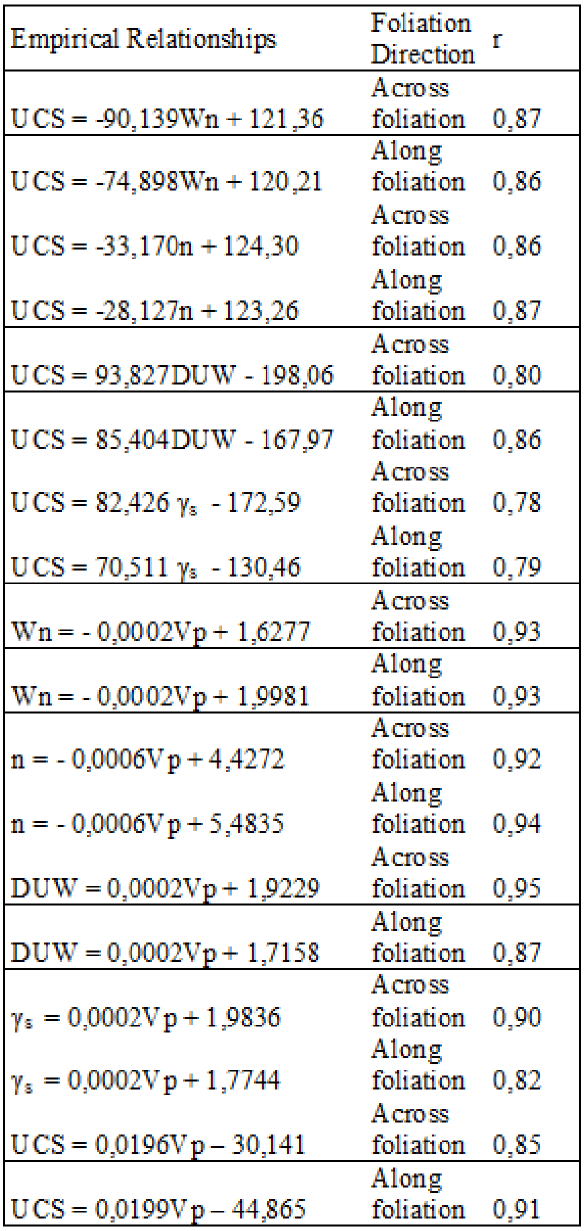
Figure 11. *Scatter plot of Saturated unit weight (γ_s) against Vp for cubic specimens with respect to a) across foliation, b) along foliation.*



a **b**

Figure 12. *Scatter plot of UCS against Vp for cubic specimens with respect to a) across foliation, b) along foliation.*

Table 3. *Empirical relationships and engineering properties obtained by laboratory studies*



Empirical Relationships	Foliation Direction	r
UCS = -90,139Wn + 121,36	Across foliation	0,87
UCS = -74,898Wn + 120,21	Along foliation	0,86
UCS = -33,170n + 124,30	Across foliation	0,86
UCS = -28,127n + 123,26	Along foliation	0,87
UCS = 93,827DUW - 198,06	Across foliation	0,80
UCS = 85,404DUW - 167,97	Along foliation	0,86
UCS = 82,426 γ_s - 172,59	Across foliation	0,78
UCS = 70,511 γ_s - 130,46	Along foliation	0,79
Wn = - 0,0002Vp + 1,6277	Across foliation	0,93
Wn = - 0,0002Vp + 1,9981	Along foliation	0,93
n = - 0,0006Vp + 4,4272	Across foliation	0,92
n = - 0,0006Vp + 5,4835	Along foliation	0,94
DUW = 0,0002Vp + 1,9229	Across foliation	0,95
DUW = 0,0002Vp + 1,7158	Along foliation	0,87
γ_s = 0,0002Vp + 1,9836	Across foliation	0,90
γ_s = 0,0002Vp + 1,7744	Along foliation	0,82
UCS = 0,0196Vp – 30,141	Across foliation	0,85
UCS = 0,0199Vp – 44,865	Along foliation	0,91

With this aim rock specimens were collected from 9 different locations in the investigation area and seismic and electric resistivity studies were completed at four different points (Fig. 1). Serpentinized ultrabasics at the same depth in the layer under the 4th measurement point had P and S seismic velocities of 5149 m/s and 2628 m/s, respectively (Table 1). At the depth of these rocks, the common electric resistivity values varied from 1200 **Ω** m and 3400 **Ω** m. This broad resistivity value interval is due to refractions by natural fractures or porosity in the serpentinized ultrabasic rocks in the field.

When the P seismic velocity value from the same depth layer in the field is examined, it varied between 4600 m/s and 4700 m/s. Thus the resistivity and seismic velocity values in the field were in accordance in terms of lithology. According to the microtremor field results, the mean period was 0.1 s, indicating compact (tight) environment and high P wave velocity. The broad interval calculated for horizontal/vertical (H/V) strength ratio indicated that the environmental parameters may vary with direction (anisotropic). Based on the Vp/Vs seismic velocity ratio obtained in the field according to the table in [42] describing alteration degree, it appears that the rocks at the 1st and 3rd seismic measurement points were “less altered rocks”, at the 2nd seismic measurement point the rocks are “very altered rocks” and the rocks at 4th seismic measurement point were classified as “unaltered rocks”. According to the table in [43], if classification according to soil-rock compaction is made, at the 1st, 3rd and 4th seismic points the rocks are “very loose” with rocks at the 2nd seismic point “compact-tight”. The results of studies on the sample groups found density values varied from 2.69 g/cm^3 and 3.41 g/cm^3. Thus, as density increased, the volume (n) and weight water absorption (Wn) capacity and cavity rate reduces. The porosity values of the rock vary from 0.01 to 0.05. In this situation, if classified according to % porosity in [44], the rock is clearly in the “very compact” rock class. If classified according to uniaxial compressive strength as in [45], the groups perpendicular to foliation A1, B1, B2, B3 and C1 and the groups parallel to foliations of A1, B1, B2, B3, C1, D1 and G1 are in the “moderate strength rock” class. From the perpendicular group D1, E1, E2 and G1 and from the parallel group E1 and E12 rock samples are in the “high strength rock” class. The compressive strength values (UCS) in the groups perpendicular to foliation varied from 52.64 MPa to 115.64 MPa and in groups parallel to foliation varied from 70.04 MPa to 121.05 MPa. This study clearly revealed that based on the data for geomechanical properties of serpentinized ultrabasic rocks, these rocks can be easily used as decorative stones, for interior-exterior decoration and in construction sector.

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