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Examination of the Physical Properties of Saturated and Dry Marbles via P-S Wave Velocity

Eshaq Ali MOHAMMADI[*1] ORCID *0000-0001-8815-372X*
Özen KILIÇ[2] ORCID *0000-0002-8398-0897*

[1]*Jawzjan University, Faculty of Geology and Mining, Department of Mining Engineering, Sheberghan, Afghanistan*
[2]*Çukurova University, Faculty of Engineering, Department of Mining Engineering, Adana*

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Abstract

In this study, ten marble samples collected from different regions of Turkey were tested in the laboratory in terms of physical properties and P-S wave velocity. The destructive method used to determine the physical properties of marbles is time-consuming, can only be tested in the laboratory, and high cost of equipment. For this reason, in order to obtain an easy to apply method, not expensive and time consuming, the relationship between saturated and dry P-S wave velocity and physical properties was investigated by regression analysis. Results of regression analyses showed satisfactory correlations.

Keywords: Marble, Physical properties, P and S wave velocity

P-S Dalga Hızı ile Doygun ve Kuru Mermerlerin Fiziksel Özelliklerinin İncelenmesi

Öz

Bu çalışmada, Türkiye'nin farklı bölgelerinden alınan 10 farklı mermer örneği fiziksel özellikleri ve P-S dalga hızının belirlenmesi amacıyla laboratuarda deneylere tabi tutulmuştur. Fiziksel özellikleri belirlemede kullanılan deneyler zaman alıcıdır, sadece laboratuar ortamında gerçekleştirilir ve oldukça maliyetlidir. Bu nedenle, daha kolay, ucuz ve daha az zaman alan bir yöntem elde etmek amacı ile doygun ve kuru örneklerde P-S dalga hızı ve fiziksel özellikler arasındaki ilişki regresyon analizleri ile incelenmiştir. Regresyon analizlerinin sonuçları tatmin edici korelasyonlar göstermiştir.

Anahtar Kelimeler: Mermer, Fiziksel özellikler, P ve S dalga hızı

[*]Corresponding author (Sorumlu yazar): Eshaq Ali MOHAMMADI, *eshaqmohammadi@yahoo.com*

1. INTRODUCTION

In designing underground and surface construction projects such as tunnels, caves, stone columns, dams and etc. it is extremely important to know the physical and mechanical properties of stones. Usually, the physical properties of rocks are determined by destructive and non-destructive methods. In the destructive method, the samples are first brought to the laboratory from the area, and after cutting to appropriate sizes, the test operation is performed. This is a long, uneconomical, and time-consuming process. The non-destructive method is based on the P and S wave velocities. P and S waves velocity is mostly used as an alternative method. Some factors affect on the speed of P and S wave such as rock type, fracture, crack, grain size and shape, porosity, water absorption, clay content, degree of erosion, texture, confining pressure, and temperature. and some mechanical properties of the rocks.

The P and S wave velocity is widely used in various sectors. In the mining is used to determine the physicomechanical properties of rocks [1], the quality of blocks [2], blast efficiency [3], blast system design [4], damage assessment of supporting pillars in an underground cave [5]. In the construction is used to evaluate the stability of walls, columns, and concrete [6]. In tunneling, is used for the reliability assessment of tunnel [7].

A number of researchers such as; Leucci and Leucci, De Giorgi [8], Khandelwal and Ranjith [9], Khandelwal and Singh [10], Moradian and Behnia [11], Kurtuluş and Çakır [12], Kurtuluş et al. [13], Karaman et al. [14], Karaman and Kesimal [15], Babacan et al. [16], Uyanık et al. [17], Boulanouar et al. [18], Karakul et al. [19], Ozdemir and Sarıcı [20], Sakcalı et al. [21], Celik [22], Kahraman et al. [23], have studied the relationship between P-wave velocity and physicomechanical properties of natural rocks. As a result, they have found equations with a high correlation coefficient.

In this study, in order to easily estimate the physical properties of marble, the relationship between saturated and dry P-S wave velocity has been investigated. As a result, equations with high correlation coefficients are found.

2. MATERIAL AND METHOD

2.1. Material

In this research, ten different types of marble specimens have been collected from different parts of Turkey. The trade name, location, and properties of the marble specimens are described in Table 1.

2.2. Determination of Physical Properties

In order to determine the physical properties such as saturated unit volume weight (U_s), dry unit volume weight (U_d), water absorption by weight (w_w), and porosity (n′). The test was performed according to the TSE (Turkish Standards Institute) [24]. Firstly the samples were cut into cubes with dimensions of 4×4×4 and 5×5×5 cm^3 as Figure 1. The samples are immersed in distilled water for 48 hours until completely wet and also they are dried in an oven set at (105±5) °C for 24 hours until reach a constant weight. The results of the physical properties test are given in Table 3.

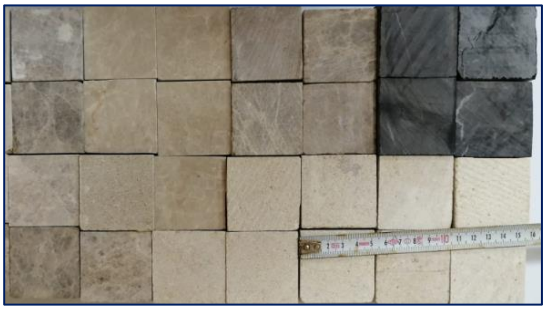

Figure 1. Specimens prepared for testing

2.3. P and S Wave Velocity

The P-wave (primary or pressure) and S-wave (secondary or shear) velocity method is a non-destructive method that is measured by Proceq Inc as shown in Figure 2. This device consists of two transducers (a transmitter and a receiver), and a time display screen. The frequency of transducers– are 54 kHz for P-wave and 150 kHz for S-wave.

Samples are prepared in the form of cubes with smooth surfaces. In order to ensure complete contact between the sample surface and the converters, their surfaces are lubricated with grease. Samples that wet in water for 48 hours and dried at 24 hours in an oven set at (105±5) °C are tested in terms of saturated and dry P-wave velocity (Vp_s, Vp_d), saturated and dry S-wave velocity (Vs_s, Vs_d). The velocity of P and S-wave is obtained by Equation 1. Results are given in Table 2.

$$V = \frac{L}{t} \tag{1}$$

Where; .V is hte velocity (km/s), L is the traveling distance (cm) and t is the traverling time (second).

Figure 2. Ultrasonic waves tester

Table 1. The trade names, locations and properties the marble specimens

No	Trade Names	Locations	Properties
1	Marble	İskenderun/Hatay	It has cracks, its color is often black with white lines.
2	Emperador	Center/Adiyaman	It hasn't cracks, its color is often light brown.
3	Emperador	Silifke/Mersin	It hasn't cracks, its color is often light brown with white lines
4	Crema	Erdemli/Mersin	It hasn't cracks, ıts color is often yellowish-white with brown lines.
5	Crema	Pozanti/Adana	It has cracks, and breaks easily, its color is yellowish-white
6	Marble	Yunak/Konya	It hasn't cracks. İts color is often gray with white lines
7	Marble	Center/Karaman	It hasn't and cracks. Its color is gray.
8	Marble	Sogut/Bilecik	It hasn't cracks. Its color is gray.
9	Marble	Center/Sivas	It hasn't cracks. Its color is gray.
10	Limestone	Hani/Diyarbakır	It has a little apparent porosity but no crack. Its color is often yellowish-white

Table 3. The average amount of physical properties of marble obtained as a result of the experiment

Rock type	U_s (g/cm³)	U_d (g/cm³)	w_w (%)	n′ (%)	Vp_s (km/s)	Vp_d (km/s)	Vs_s (km/s)	Vs_d (km/s)
Marble	2.734	2.731	0.155	0.462	6.048	6.015	3.828	3.808
Emperador	2.691	2.673	0.650	1.740	6.112	6.077	3.893	3.871
Emperador	2.705	2.690	0.555	1.664	6.234	6.105	3.996	3.913
Crema	2.704	2.694	0.124	0.217	6.454	6.371	4.246	4.191
Crema	2.635	2.600	0.653	0.965	5.206	5.134	3.295	3.249
Marble	2.665	2.622	0.524	0.926	5.394	5.337	3.414	3.378
Marble	2.656	2.656	0.476	0.895	5.573	5.466	3.527	3.459
Marble	2.666	2.664	0.346	0.654	5.769	5.716	3.651	3.595
Marble	2.695	2.688	0.260	0.684	6.483	6.407	4.210	4.161
Limstone	2.621	2.557	2.543	6.434	4.613	3.945	2.920	2.497

3. RESULTS AND DISCUSSIONS

The relationship between physical properties with saturated and dry P-S wave velocity has been investigated by various simple regression models such as linear, logarithmic, quadratic, cubic, power, and exponential. The models are compared with each other in terms of mean square errors (MS) and correlation coefficients (R^2). The model with the least means square error and the highest correlation coefficient has been selected as the appropriate model.

The exponential model has been found for the relationship between (U_s) with (Vp_s), (Vp_d), and (Vs_d) by high correlations such as (R^2= 0.749), (R^2= 0.71) and (R^2= 0.697) Figure 3-5, and also for the relationship between (U_d) with (Vp_d), the exponential model with a high correlation (R^2= 0.834) has been received Figure 6. The equations of these relations are given below:

$$U_s = 2.391 \times e^{0.02 \times Vp_s} \quad (2)$$

$$U_s = 2.457 \times e^{0.015 \times Vp_d} \quad (3)$$

$$U_s = 2.47 \times e^{0.022 \times Vs_d} \quad (4)$$

$$U_d = 2.314 \times e^{0.0225 \times Vp_d} \quad (5)$$

For the relationship between (U_s) with (Vs_s), the power model with high correlation (R^2= 0.716) has been received in Figure 7. The equation of relation is as given below.

$$U_s = 2.359 \times {Vs_s}^{0.098} \quad (6)$$

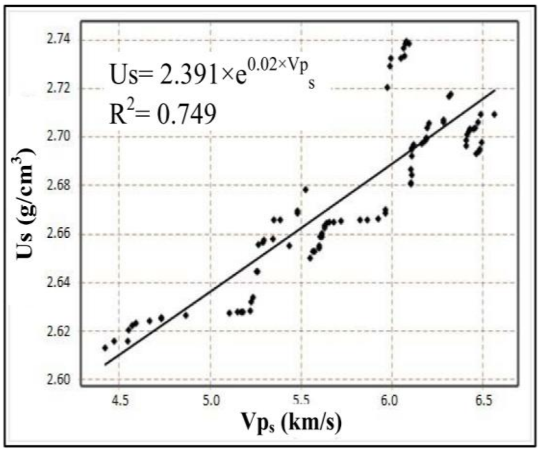

Figure 3. Graph of relationship between U_s and Vp_s

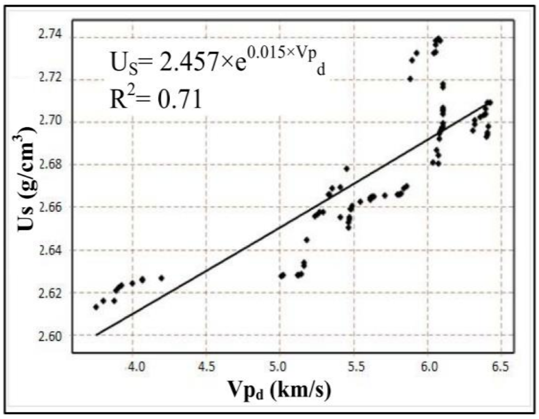

Figure 4. Graph of relationship between U_s and Vp_d

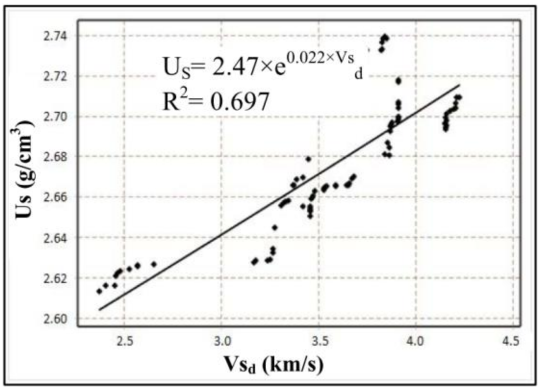

Figure 5. Graph of relationship between U_s and Vs_d

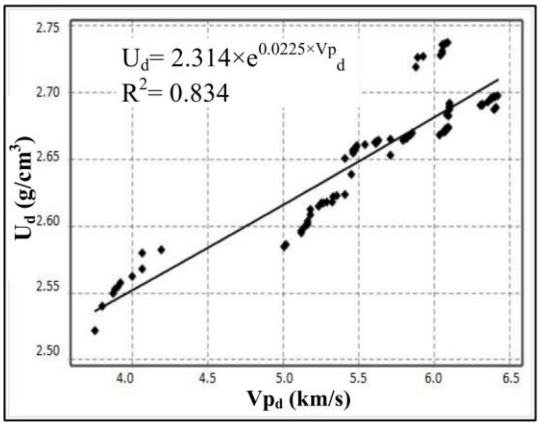

Figure 6. Graph of relationship between U_s and Vp_d

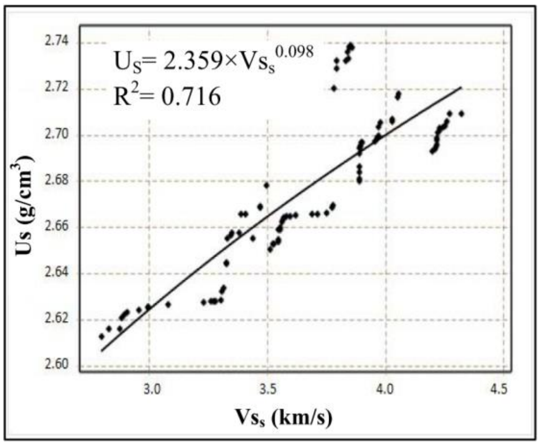

Figure 7. Graph of relationship between U_s and Vs_s

The power model has been found for the relationship between (U_d) with (Vp_s), (Vs_s), and (Vs_d) with high correlations such as (R^2= 0.84), (R^2= 0.80) and (R^2= 0.80) Figure 8-10., and also for the relationship between (n′) with (Vp_s), (Vp_d), (Vs_s), and (Vs_d), the power model with middle correlations such as (R^2= 0.458), (R^2= 0.544), (R^2= 0.467), and (R^2= 0.553), has been received in Figure 11-14. The equations of these relations are given below:

$$U_d = 1.97 \times Vp_s^{0.017_d} \quad (7)$$

$$U_d = 2.314 \times Vs_s^{0.153} \quad (8)$$

$$U_d = 2.314 \times Vs_d^{0.0116} \quad (9)$$

$$n' = 24474.087 \times Vp_s^{-5.8} \quad (10)$$

$$n' = 48258.6 \times Vs_s^{-8.45} \quad (11)$$

$$n' = 2980.57 \times Vp_d^{-4.67} \quad (12)$$

$$n' = 288.88 \times Vs_d^{-4.5} \quad (13)$$

There are quadratic model for the relationship between (w_w) with (Vp_s), (Vp_d), (Vs_s) and (Vs_d) with very high correlations such as (R^2= 0.866), (R^2= 0.932), (0.935) and (R^2= 0.938) Figure 15-18. The equations of these relations are given below:

$$w_w = 37.7 - 12.4 \times Vp_s + 1.03 \times Vp_s^2 \quad (14)$$

$$w_W = 18 - 5.8 \times Vp_d + 0.47 \times Vp_d^2 \quad (15)$$

$$w_W = 31.8 - 16.1 \times Vs_s + 2.06 \times Vs_s^2 \quad (16)$$

$$w_W = 16.7 - 8.4 \times Vs_d + 1.07 \times Vs_d^2 \quad (17)$$

The Saturated and dry P-S wave velocity as independent variables and physical parameters as dependent variables were examined by multiple regression analysis. As a result of the analysis, the equations obtained have high correlations such that for saturated unit volume weight (R^2= 8188), for dry unit volume weight (R^2= 0.8908), for porosity (R^2= 0.9135), and for water absorption (R2= 0.9311).

$$U_S = 2.2 + 0.8 \times Vp_S - 0{,}58 \times Vp_d - 1{,}1 \times Vs_S + 0{,}8 \times Vs_d \quad (18)$$

$$U_d = 2 + 0.5 \times Vp_s - 0.18 \times Vp_d - 0.6 \times Vs_s + 0{,}26 \times Vs_d \quad (19)$$

$$W_w = 1.8 + 6.2 \times Vp_s - 5.9 \times Vp_d - 5.8 \times Vs_s + 4.86 \times Vs_d \quad (20)$$

$$n' = -0.4 + 22.9 \times Vp_s - 19 \times Vp_d - 22 \times Vs_s + 16 \times Vs_d \quad (21)$$

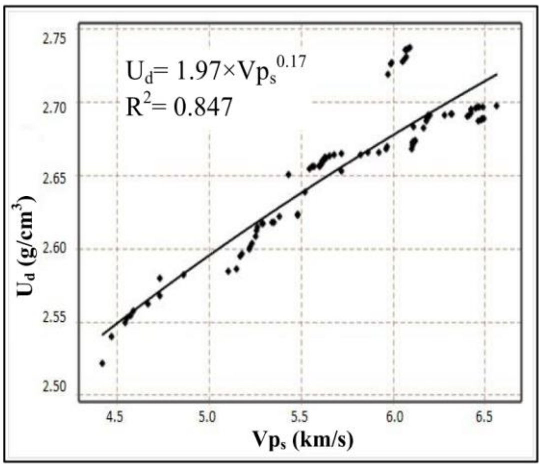

Figure 8. Graph of the relationship between U_d and Vp_s

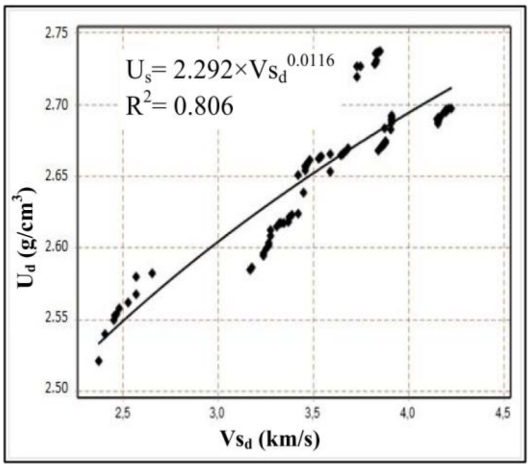

Figure 10. Graph of the relationship between U_s and Vs_d

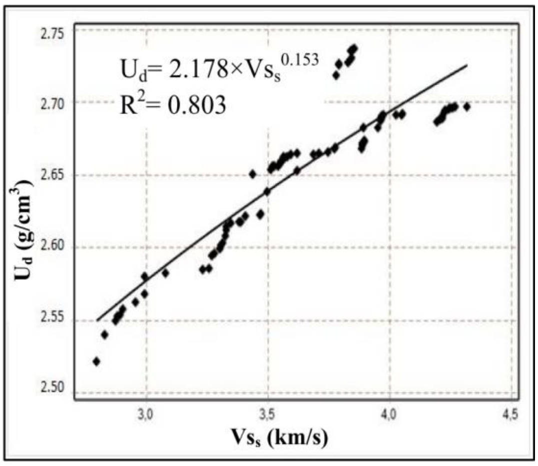

Figure 9. Graph of the relationship between U_d and Vs_s

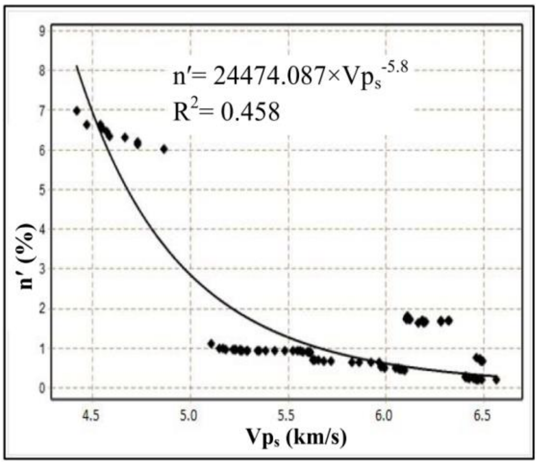

Figure 11. Graph of the relationship between (n′) and Vp_s

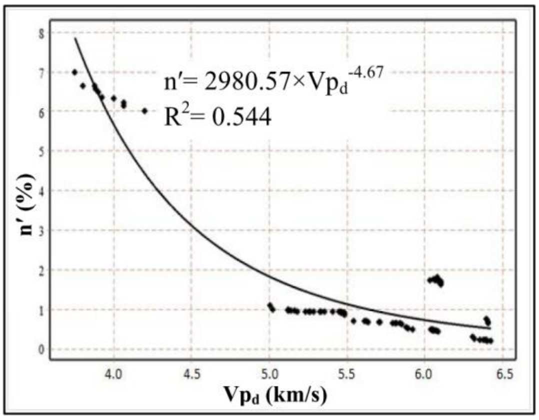

Figure 12. Graph of the relationship between (n′) and Vp_d

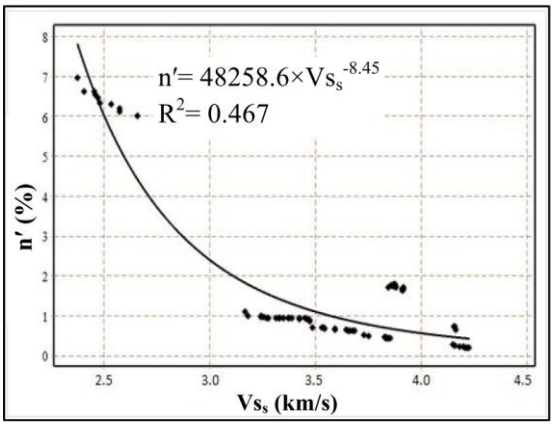

Figure 13. Graph of the relationship between (n′) and Vs_s

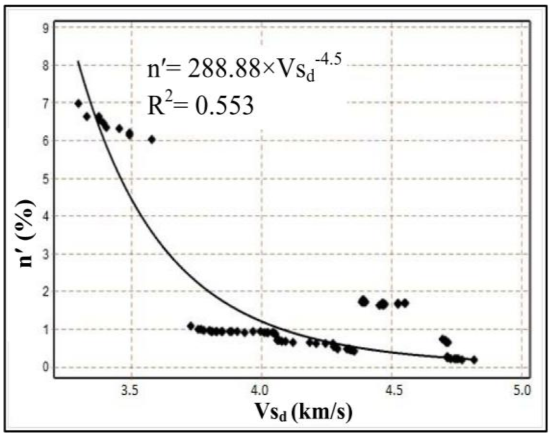

Figure 14. Graph of the relationship between (n′) and Vs_d

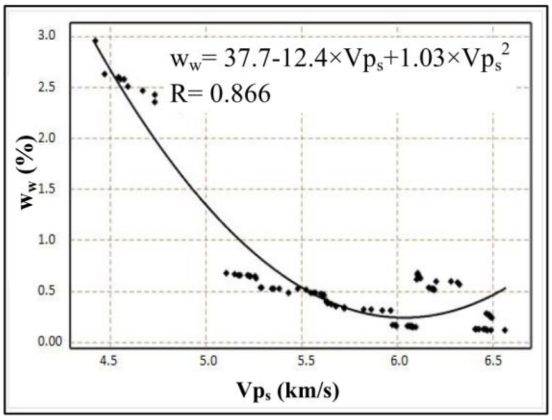

Figure 15. Graph of the relationship between w_w and Vp_s

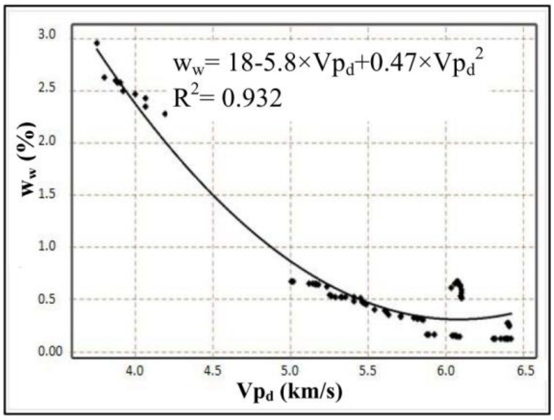

Figure 16. Graph of the relationship between w_w and Vp_d

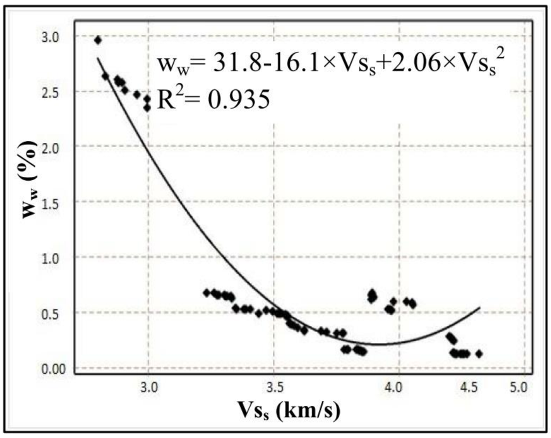

Figure 17. Graph of the relationship between w_w and Vs_s

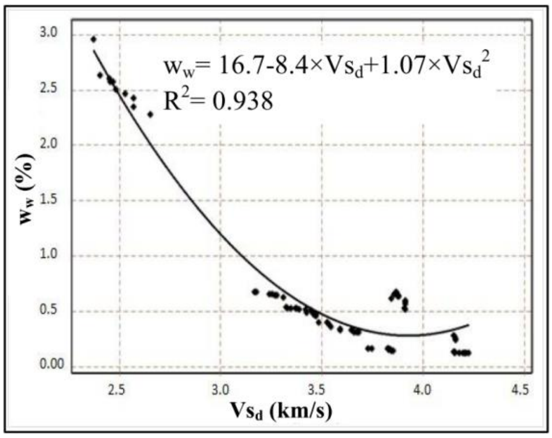

Figure 18. Graph of the relationship between w_w and Vs_d

4. CONCLUSIONS

As a result, among the samples, Diyarbakir limestone has the most water absorption and porosity, which does not adapt to the standard of TSE-1469. The relationship between the saturated and dry P-S wave velocity with saturated and dry unit volume weight is direct but inverse with porosity and water absorption. The equations obtained as a result of simple and multiple regression analysis have a high correlation coefficient and a lower mean square error that can be used in practice. The equations obtained as a result of multiple analyses have the lowest mean square error than simple regression, so its use is recommended if possible.

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