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Linear Regression and Spearman Rank Correlation Analyses of P-wave Velocity (Vp) and Rock Quality Designation (RQD) of Karacadağ Volcanics, Southeast Türkiye

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Abstract The importance of geotechnical and geophysical investigations is significant, not only for the physical properties of the soil but also for its lithological, physical, and geomechanical characteristics from an engineering perspective. In this study, linear regression and Spearman rank correlation analyses were performed between the P-wave velocity (Vp) obtained from seismic refraction measurements applied to the Karacadağ volcanites exposed in and around the city centre of Diyarbakır and the rock quality designation (RQD) obtained from core drilling. In regression analyses for Karacadağ volcanites exposed in the city centre of Diyarbakır, the regression analyses between RQD and Vp-wave velocity for Gravel-sized clay-bound block basalt+Basalt, which makes up all the soil units, resulted in R^2=0. 9298 has been calculated. It was determined that there were linearly very strong relationships between RQD and P-wave velocity in all units. In Spearman's rank correlation analysis for the Karacadağ volcanites exposed in the Diyarbakır city centre, the Spearman's rank correlation (r_s) results showed a significant strong relationship between RQD and Vp (r (47) = 0.97852, p< 0.0001). In geotechnical investigations, integrated applications where many parameters are evaluated using different methods are quite advantageous. It was observed that the seismic velocities obtained by geophysical methods for the units in the study area, the rock quality designation (RQD) determined within the scope of geotechnical analyses, and the P-wave velocity (Vp) results supported each other.

Keywords Basalt · Karacadağ Volcanics · P-wave Velocity (Vp) · Rock Quality Designation (RQD) · Linear Regression Analysis · Spearman Rank Analysis

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Introduction

In engineering projects, the investigation of rock mass properties is carried out by determining their seismic velocities and geomechanical characteristics. In recent years, there has been an increase in geotechnical and geophysical research and applications aimed at explaining not only the physical properties of soils but also their lithological, physical, and geomechanical properties, which are the engineering properties of soils (Keçeli, 2010). P (longitudinal, compression-expansion) and S (transverse, shear-torsion) seismic wave velocities, which provide direct information for determining the physical properties of geological units such as their rigidity, hardness, porosity, and weathering levels, can be used reliably (Braybrooke, 1988).

Therefore, in addition to geological surveys, the use of geophysical techniques to determine the strength characteristics of rock masses leads to more accurate and reliable results. The P and S wave velocities of geological units can be determined in the field using the seismic refraction and multichannel surface wave analysis (MASW) methods, respectively. The rippability classes can be quickly and reliably estimated based on the distribution of seismic velocities in 1D and 2D and their relationship to the geotechnical properties of geological units. Seismic velocities can vary within the same geological unit depending on changes in the unit's physical properties. Generally, seismic wave velocity increases as the density-rigidity of a geological unit increases, while it decreases as these properties weaken. For example, a granite rock can change from a completely weathered state (soil formation) to a solid state within a P-wave velocity range of ~1600-6500 m/s (Karslı et al., 2021).

Sjøgren et al., (1979) derived some rock mechanical parameters, such as the number of fractures and the Rock Quality Designation (RQD), from the values of compression wave velocity and obtained an average regression curve for different rock types through a comprehensive study on borehole log samples.

Many researchers have studied the relationship between rock properties and P-wave velocity. Several rock properties, including density, porosity, slake durability index, uniaxial compressive strength, modulus of elasticity, slake hardness, and Sharma & Singh (2008) are correlated with P-wave velocity (Yagiz, 2011; Khandelwal, 2013). Evidenced by studies conducted by McCann et al. (1990); McDowell (1993); El-Naqa (1996); Budetta et al. (2001); Bery & Saad (2012); Fathollahy et al. (2017); and Nourani et al. (2017). Moreover, regression analyses and correlation analyses were studied for many earth scientists for different variables (Schuenemeyer & Drew, 2011; Walford, 2025; Tunç & Alpaslan, 2025).

In this study, a neighbourhood was chosen from Diyarbakır city centre (Figure 1a). Regression and Spearman rank correlation analyses were performed between the P-wave velocity (Vp) obtained from seismic refraction measurements applied to the Karacadağ volcanites exposed in and around the city centre of Diyarbakır and the rock quality designation (RQD) obtained from core drilling. Within the scope of this study, regression and Spearman rank correlation analyses were performed between the RQD values of the Karacadağ volcanites exposed in and around the city centre of Diyarbakır and the Vp (m/s) values obtained from the seismic refraction method. In the study area, 7 seismic refraction studies were conducted to determine the engineering properties of the units present (Figure 1b). Seismic refraction measurements were completed along a 55 m profile with a 5 m geophone spacing, a 2.5 m offset, and 12 geophones at 4.5 Hertz. From these measurements, the P-wave velocities of elastic waves propagating within the basalt rocks, which are the dominant rock type in the working area, were calculated. However, a total of 16 boreholes (Figure 1b), each 130 metres in depth, were drilled to determine the engineering and geological properties of the soil.

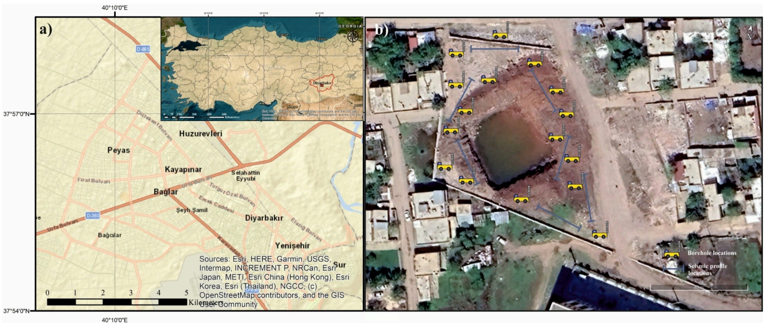

Figure 1. Site area: a) Location of Diyarbakır city b) Boreholes and seismic profiles locations

The study area is in Türkiye's Southeastern Anatolia Region but is close to where the Arabian Plate and the Eurasian continent collide (Figure 2). As a result of this collision, an E-W trending shear zone was formed passing through the north of Diyarbakır. Metamorphic rocks and ophiolitic rock associations are widely exposed along this suture zone (Güven et al., 1991). The study area and its surroundings have been subjected to significant tectonic events within geological processes, resulting in the development of numerous tectonic structures. The Miocene-Pliocene-aged Şelmo Formation and the Quaternary-aged Karacadağ volcanites are exposed in and around Diyarbakır. The unit, composed entirely of basaltic lavas and rare pyroclastics, is named Karacadağ Volcanites

(Figure 2). The unit is generally composed of basaltic lavas, and petrographic studies have identified it as olivine basalt and olivine-augite basalt (Bağırsakçı et al., 1995). The basalts located northwest of Diyarbakır are enormous, cut by regular fracture systems, and appear as solid blocks of varying sizes on the surface (Ercan et al., 1991). In the study area, the Karacadağ Volcanites are unconformably situated on the Upper Miocene-Pliocene-aged Şelmo Formation, which is composed of an alternation of conglomerate, sandstone, and mudstone. The Karacadağ volcanism is represented by basic lavas. Three main eruption periods have been identified in its volcanism (Şaroğlu & Emre, 1987).

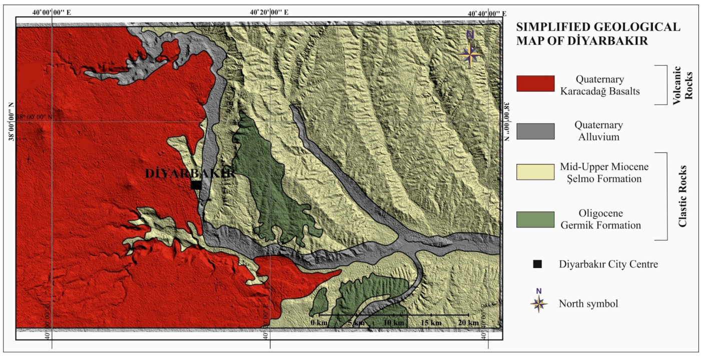

Figure 2. Simplified geological map of Diyarbakır adapted from Turhan et al., 2002

Materials and Methods

The seismic refraction method is used to determine the compressional (P-wave velocity) and shear (S-wave velocity) wave velocities of underground structures. This method is widely and effectively used in the study of the geomechanical properties of rock masses. This method, developed using the theory of sound wave propagation in a homogeneous elastic medium, is one of the most advanced geophysical methods in terms of application and technology and is one of the most powerful and oldest geophysical methods for investigating the rock's properties (Sjøgren et al., 1979; Barton, 2007; Ghanbari et al., 2013). Currently, the method is the most suitable for determining rock quality before the construction of structures such as bridges, tunnels, dams, subways, nuclear power plants, and other important massive facilities, and for investigating the presence of weak rock (Klimis et al., 1999). Specifically, the P-wave velocity test, which can be performed both in the laboratory and in the field, is a non-destructive testing method widely used in construction, geotechnical, and mining projects such as underground excavation, quarrying, blasting, and drilling (Yagiz, 2011). P-wave velocity is correlated with the basic parameters of rock mechanics, namely fracture frequency and RQD, where P-wave velocity decreases as the number of joints increases (Kahraman, 2001). Therefore, the concept of RQD, which are the basic parameters of rock mechanics, was proposed by Deere et al., (1967) and expressed as the ratio (in percentage) of the total length of intact rock core pieces, which retain their cylindrical shape and are divided by natural discontinuities, with a length of 10 cm or greater, to the length of the advance.

Results and Discussion

In the study area, 16 boreholes were drilled, and at a depth of approximately 1.50 metres from the surface, excavations or clay from old foundations are found, followed by fractured, cracked, and locally intensely weathered Pliocene-Quaternary-aged Karacadağ Basalts (Figure 3). The samples obtained for the study area (Figure 4) were classified as local soil class ZB according to TBEC (2018) when evaluating the laboratory test results, geophysical measurement results, and the structure of the soil/rock.

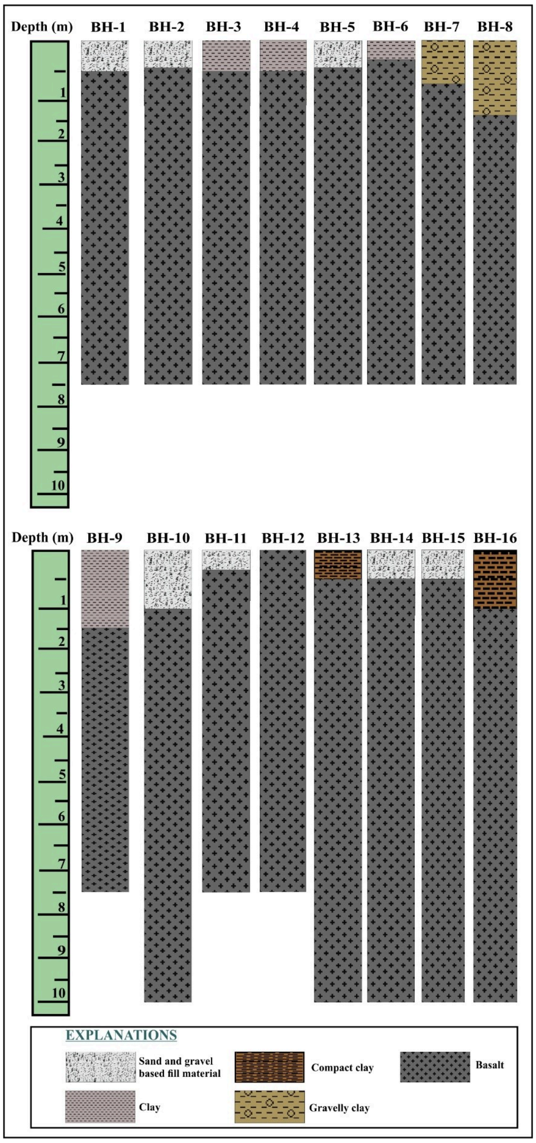

Figure 3. Borehole logs in the study area

Table 1. Rock quality (RQD) and weathering properties based on boreholes drilled in the study area

Borehole No	Depth (m)	RQD (%)	Weathering	Borehole No	Depth (m)	RQD (%)	Weathering	Borehole No	Depth (m)	RQD (%)	Weathering
BH-4	0.00-1.50	63	W2	BH-1	0.00-2.00	65	W2	BH-6	0.00-2.00	77	W1
	1.50-4.00	12	W3-W4		2.00-4.00	22	W3-W4		2.00-4.50	35	W2-W3
	4.00-6.00	72	W2		4.00-5.00	95	W1		4.50-6.50	30	W2-W3
	6.00-7.50	80	W2		5.00-7.50	48	W2		6.50-7.50	88	W1
BH-5	0.00-1.50	33	W3	BH-2	0.00-2.00	60	W2	BH-8	0.00-1.40	-	-
	1.50-4.50	0	W4		2.00-4.50	24	W3-W4		1.40-4.50	0	W4
	4.50-7.50	55	W2		4.50-7.50	5	W4		4.50-7.50	24	W3
BH-7	0.00-1.50	23	W3-W4	BH-3	0.00-2.00	30	W3-W4	BH-9	0.00-1.50	-	-
	1.50-4.50	24	W3-W4		2.00-4.50	0	W4		1.50-4.50	18	W3-W4
	4.50-7.50	40	W2		4.50-7.50	45	W2-W3		4.50-7.50	41	W2
BH-13	0.00-1.50	52	W2	BH-10	0.00-1.00	-	-	BH-16	0.00-1.00	-	-
	1.50-4.50	16	W3		1.00-4.00	48	W2		1.00-4.00	13	W3-W4
	4.50-6.50	30	W2		4.00-6.00	31	W2		4.00-6.50	6	W4
	6.50-7.50	85	W2		6.00-7.00	40	W2		6.50-7.50	30	W2
	7.50-10.00	56	W2		7.00-10.00	83	W1		7.50-10.00	74	W1
BH-11	0.00-2.50	0	W5	BH-14	0.00-1.50	60	W2	BH-15	0.00-2.00	56	W2
	2.50-5.00	20	W2		1.50-4.50	5	W3-W4		2.00-4.50	0	W4
	5.00-7.50	36	W2		4.50-7.00	44	W2		4.50-7.50	35	W2
BH-12	0.00-1.50	0	W4		7.00-10.00	86	W2		7.50-10.00	88	W1
	1.50-4.50	6	W3-W4								
	4.50-7.50	54	W2-W3								

Figure 4. Appearance of a basalt sample taken from the study area borehole

In geotechnical analyses, the basalt units forming the Karacadağ volcanites generally correspond to good-quality rock, with RQD classifications ranging from 77% to 88%. However, in a smaller proportion, they exhibit very poor-quality rock characteristics with brownish clay on intensely fractured surfaces and occasional gravel-sized weathered levels (Table 1, Table 2). According to ISRM (1978), the basalt unit forming the Karacadağ volcanites is classified as slightly weathered (W2), moderately weathered (W3), and highly weathered (W4) (Table 3).

Table 2. Classification of rock types according to rock quality designation (RQD) (Deere & Miller, 1966)

Classification of rock types according to rock quality (RQD) (Deere & Miller, 1966)	
Rock Quality (RQD)	Rock quality designation
0-25	Very poor
25-50	Poor
50-75	Fair
75-90	Good
90-100	Excellent

During the propagation of P waves, there is cubic expansion or a change in volume due to compression. The direction of vibration, representing compression and expansion in longitudinal waves, is the same as the direction of wave propagation. Therefore, in compressible soils, the P-wave velocity will be low, while in soils that are difficult to compress (rock), the P-wave velocity will be high. Accordingly, the rock rippability degrees based on the P-wave velocity are given in Table 4. Based on the variation of P-wave velocities obtained from seismic profiles in the study area, two different

Table 3. Weathering classification according to ISRM (1978)

Description of rock mass conditions	Term	Weathering grade
No visible sign of rock material weathering; perhaps slight discolouration on major discontinuity surfaces	Fresh rock	W1
Discolouration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discoloured by weathering and may be somewhat weaker than its fresh condition.	Slightly weathered	W2
Less than half of the material is decomposed and/or disintegrated to a soil. Fresh or discoloured rock is present, either as a continuous framework or as corestones.	Moderately weathered	W3
More than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discoloured rock is present, either as a discontinuous framework or as corestones.	Highly weathered	W4
All rock material is decomposed and/or disintegrated to soil. The original mass structure is still largely intact.	Completely weathered	W5
All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.	Residual soil	W6

geological units (Figure. 5) were evaluated from the surface. Accordingly, the geological units located from the surface in this profile are rippable as 'Very Easy' (Vp<900 m/s) in the gravel-sized clay-bound block basalt unit, where seismic velocities are between 476 and 514 m/s in the first layer, and as 'Very Difficult' (Vp>2100 m/s) for the basalt unit in the second layer, where Vp velocities are between 2100 and 2245 m/s (Figure 5).

Table 4. Depending on the P-wave velocity, the rippability of soils or rocks (Keçeli, 2012)

P-wave velocity (m/s)	Rippability
300-600	Very easy
600-900	Easy
900-1500	Moderate
1500-2100	Hard
2100-2400	Very hard
2400-2700	Extremely hard

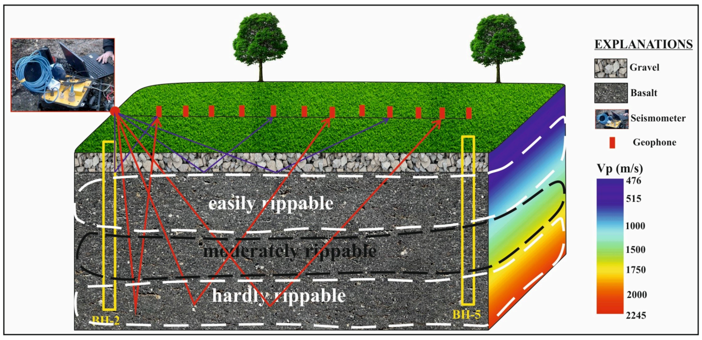

Figure 5. Underground section showing the degree of rippability of basalts in the study area based on P-wave velocity

Linear Regression of RQD with P-Wave Velocity

In this study, a relationship was established between the variables using 49 pairs of RQD and Vp data in regression and Spearman rank correlation analyses for the Karacadağ volcanites exposed in the city centre of Diyarbakır. The linear regression graphs between RQD and Vp for the 16 boreholes located on the seismic profiles in the working area are presented in Figure 6 for Gravel-sized clay-bound block basalt+Basalt, which makes up all the soil units; a linear regression between RQD and Vp relationships was calculated, with R^2=0.9298 (Figure 6). In other words, when the P-wave and RQD data were examined, the coefficient of determination, or R^2 value, which explains the change in the strength of the relationship between the two variables, was found to be 0.9298. The equation supporting this ratio is given in Equation (1).

$$Y = 0.0411*X - 7.9238 \quad (1)$$

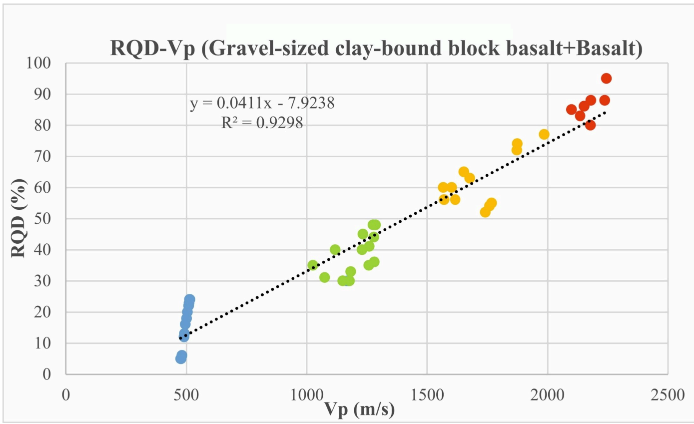

Figure 6. Gravel-sized clay-bound block basalt and basalt data set related RQD-Vp linear regression

For the gravel-sized clay-bound block basalt unit, the linear regression between RQD and Vp relationships has been calculated as R^2=0.9936 (Figure 7). For the basalt unit, the linear regression between RQD and Vp relationships has been calculated as R^2=0.9297 (Figure 8). The equations supporting these ratios are given in Equation (2) and Equation (3).

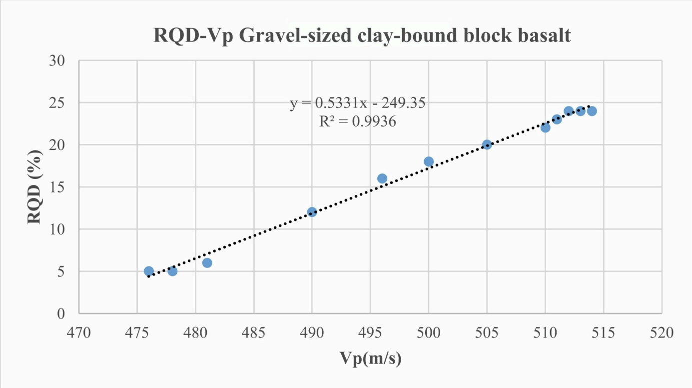

Figure 7. Gravel-sized clay-bound block basalt data set related RQD-Vp linear regression

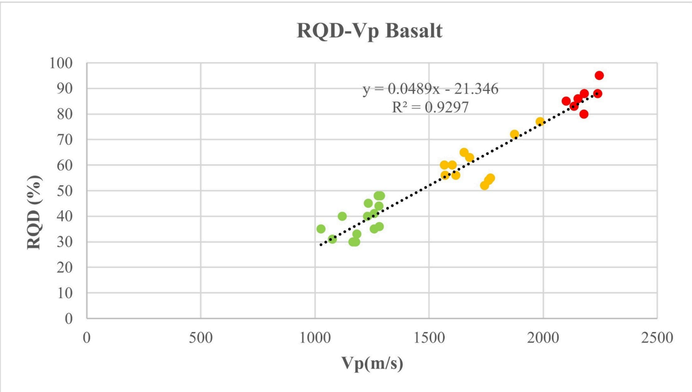

Figure 8. Basalt-related RQD-Vp linear regression

$$Y = 0.5331{*}X - 249.35 \tag{2}$$

$$Y = 0.0489{*}X - 21.346 \tag{3}$$

According to Deere & Miller (1966), RQD and Vp linear regressions for all soil units in the study area, in 14 data points, Vp: 476-514 m/s show RQD: very poor; in 16 data points, Vp: 1027-1287 m/s give RQD: poor; 11 data points with Vp: 1567-1875 m/s demonstrate RQD: fair; 7 data points with Vp: 1986-2238 m/s present RQD: good; and 1 data point with Vp: 2245 m/s exhibits RQD: excellent (Figure 9).

Spearman Rank Correlation of RQD with P-Wave Velocity

The Spearman rank correlation coefficient is calculated to check the agreement in the ranking of results between two groups. Regardless of data normality or equal variance, the Spearman rank correlation coefficient focuses on differences in the rank order of the data rather than differences in the means (Hwang et al., 2015). The Spearman coefficient is suitable for both continuous and discrete ordinal variables (Lehman et al., 2005). This coefficient is calculated as in Equation (4) (Spearman, 1904).

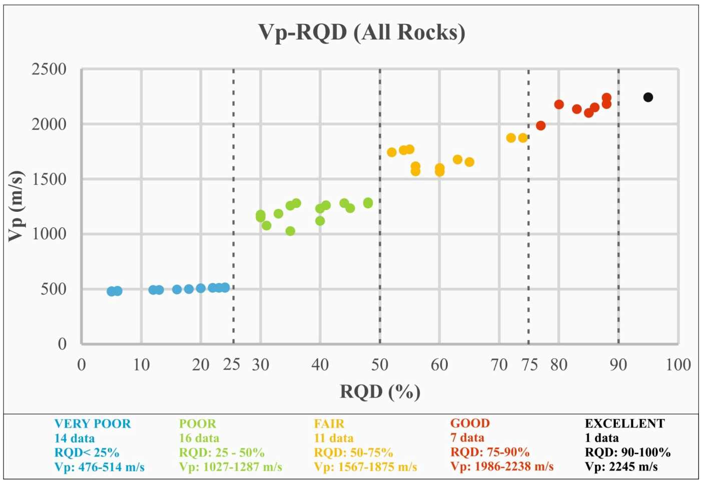

Figure 9. All rocks' rock quality classification according to Deere and Miller (1966) for this study

$$r_s = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \tag{4}$$

The value of n is the number of members of each parameter, and the difference between ranks is denoted by d_i in this relationship. The value of r_s can vary from +1 to −1. Values of r_s that are positive indicate positive correlations, while negative values indicate negative correlations. The value of r_s=0 means that no association exists.

The rank correlation (r_s), developed by Spearman (1904), is a nonparametric statistic that allows researchers to discuss how strong the relationship between two variables X and Y is without making the more stringent assumptions required for Pearson's product-moment correlation (r). To find r_s, you must convert each variable into a rank and assign equal ranks to equal values (Spearman, 1904; Gonzalez & Nelson, 1996). You can then set the sample size to N and find the differences between the ranked scores of X and Y for each case pair. This statistic examines the order of differences between closely spaced scores and does not examine how different they are, making it an ordinal statistic (Cliff, 1996). If the samples are sufficient in number, you can use a method that is close to the t distribution and has df =N–2: This *t* statistic is calculated as in Equation (5)

$$t = r_s\sqrt{\frac{n-2}{1-r_s^2}} \tag{5}$$

Spearman's rank correlation (r_s) results showed a significantly strong positive relationship between RQD and Vp for this study (r (47) = 0.97852, p< 0.0001) (Table 5). In other words, a P value close to 1 indicates a very weak correlation between RQD and Vp. If the P value is close to 1, the observed correlation is likely to be due to chance, and the probability that your null hypothesis (H_0) is true is remarkably high. In this study, since

Table 5. Spearman rank correlation data set of this study

Vp (m/s)	RQD (%)	$Rank_{Vp}$	$Rank_{RQD}$	r_s	*t* statistic	*P* (significance)
1654	65	35	39			
510	22	10	10			
2245	95	49	49			
1276	48	27	29.5			
1567	60	31	36.5			
514	24	14	13			
478	5	1	1.5			
1167	30	19	16.5			
1234	45	24	28			
1678	63	36	38			
490	12	5	5			
1874	72	40	40			
2178	80	46	43			
1183	33	22	20			
1768	55	39	33			
1986	77	42	42			
1259	35	25	21.5			
1174	30	20	16.5			
2238	88	48	47.5			
511	23	11	11			
513	24	13	13			
1230	40	23	24.5			
512	24	12	13			
500	18	8	8			
1260	41	26	26	0.97852	32.54135	< 0.0001
1287	48	30	29.5			
1076	31	16	19			
1119	40	17	24.5			
2135	83	44	44			
505	20	9	9			
1281	36	29	23			
481	6	3	3.5			
1760	54	38	32			
1743	52	37	31			
496	16	7	7			
1178	30	21	16.5			
2100	85	43	45			
1571	56	32	34.5			
1602	60	33	36.5			
476	5	1	1.5			
1280	44	28	27			
2152	86	45	46			
1617	56	34	34.5			
1027	35	15	21.5			
2180	88	47	47.5			
492	13	6	6			
482	6	4	3.5			
1150	30	18	16.5			
1875	74	41	41			

the p value is less than 0.0001, the alternative hypothesis (H_1), which states that there is a strong correlation between our data set, is accepted.

Conclusion

In this study, linear regression and Spearman Rank correlation analyses were performed between the (Vp) obtained from seismic refraction measurements applied to the Karacadağ volcanites exposed in and around the city centre of Diyarbakır, and the (RQD) obtained from core drillings.

- Seismic method results indicate the presence of two layers with different P-wave velocity values. Generally, the first layer, gravel-sized clay-bound block basalt, has a P-wave velocity between 476 and 514 m/s, and the second layer, basalt, has a P-wave velocity between 2100 and 2245 m/s.
- In geotechnical analyses, the basalt units forming the Karacadağ volcanites generally correspond to good quality rock, with an RQD classification ranging from 77% to 88%. However, in a smaller proportion, they exhibited very poor-quality rock characteristics in areas with brownish clay on intensely fractured surfaces and occasional gravel-sized weathered levels.
- In statistic correlation analyses for Karacadağ volcanites exposed in the city centre of Diyarbakır, the linear regression between RQD and Vp for Gravel-sized clay-bound block basalt+Basalt, which makes up all the soil units, resulted in R^2=0. 9298 has been calculated. In other words, when the Vp and RQD data were examined, the coefficient of determination, or R^2 value, which explains the change in the strength of the relationship between the two variables, was found to be 0.9298. In the linear regression between RQD and Vp, for the Gravel-sized clay-bound block basalt and Basalt units, respectively, R^2=0.9936 and R^2=0.9297. It was determined that there were linearly increasing relationships between RQD and Vp in all units.
- In Spearman's rank correlation analysis for the Karacadağ volcanites exposed in the Diyarbakır city centre, the Spearman's rank correlation (r_s) results showed a significant positive relationship between RQD and Vp ($r(47) = 0.97852$, $p < 0.0001$).

In geotechnical investigations, integrated applications that evaluate multiple parameters using different methods are highly advantageous. It has been observed that seismic velocities obtained using geophysical methods for units in the study area strongly support the RQD and Vp results determined within the scope of geotechnical analyses. When examining soil and rock environments affected by numerous factors, it is important to interpret the results obtained from geophysical methods and engineering geology studies together with geotechnical data.

Diyarbakır is experiencing significant developments in modern construction due to its rapidly growing population. Therefore, future geotechnical studies in the study area are of great importance. In particular, the Karacadağ volcanic rocks are one of the dominant lithological units located in the centre of Diyarbakır province. In this study, a strong relationship was found between the RQD and Vp data obtained from field studies of the Karacadağ volcanic rocks. Consequently, it is believed that our study will support the geotechnical investigations to be carried out in new constructions here.

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REFERENCES

Bağırsakçı, S., Ekber, A., Polat, C., & Kum, M. (1995). Diyarbakır-Ergani-Çınar alanının jeolojisi. Maden Tetkik ve Arama, Jeoloji Etütleri Dairesi Raporu.

Barton, N. (2007). Near-surface gradients of rock quality, deformation modulus, Vp and Qp to 1 km depth. first break, 25(10). https://doi.org/10.3997/1365-2397.2007025

Bery, A. A., & Saad, R. (2012). Correlation of seismic P-wave velocities with engineering parameters (N value and rock quality) for tropical environmental study. International Journal of Geosciences, 3(4), 749-757. https://doi.org/10.4236/ijg.2012.34075

Braybrooke, J. C. (1988). The state of the art of rock cuttability and rippability prediction. In Fifth Australia-New Zealand Conference on Geomechanics: Prediction Versus Performance; Preprints of Papers (pp. 13-42). Barton, ACT: Institution of Engineers, Australia.

Budetta, P., De Riso, R., & De Luca, C. (2001). Correlations between jointing and seismic velocities in highly fractured rock masses. Bulletin of Engineering Geology and the Environment, 60(3), 185-192. https://doi.org/10.1007/s100640100097

Cliff, N. (2014). Ordinal methods for behavioral data analysis. Psychology Press.

Deere, D. U., & Miller, R. P. (1966). Engineering classification and index properties for intact rock (No. AFWLTR65116). https://doi.org/10.21236/AD0646610

Deere, D.U., Hendron, A.J., Patton, F.D. & Cording, E.J. (1967). Design of Surface and Near Surface Constructions in

Rock, In C. Fairhurst (ed.), Proc. 8th U.S. Symp. Rock Mechanics of AIME, New York, pp. 237 – 302.

El-Naqa, A. (1996). Assessment of geomechanical characterization of a rock mass using a seismic geophysical technique. Geotechnical & Geological Engineering, 14(4), 291-305. https://doi.org/10.1007/BF00421945

Ercan, T., Şaroğlu, F., Turhan, N., Matsuda, J. I., Ui, T., Fujitani, T., ... & Gürler, H. (1991). Karacadağ volkanitlerinin jeolojisi ve petrolojisi. Türkiye Jeoloji Bülteni, 6, 118-133.

Fathollahy, M., Uromeiehy, A., & Riahi, M. (2017). Evaluation of P-wave velocity in different joint spacing. Bollettino di Geofisica Teorica ed Applicata, 58(3). https://doi.org/10.4430/bgta0208

Ghanbari, Y., Ramazi, H. R., Pazand, K., & Madani, N. (2013). Investigation of rock quality of Shirinrud dam site by engineering seismology. Arabian Journal of Geosciences, 6(1), 177-185. https://doi.org/10.1007/s12517-011-0322-7

Gonzalez, R., & Nelson, T. O. (1996). Measuring ordinal association in situations that contain tied scores. Psychological bulletin, 119(1), 159.

Güven, A., Dinçer, A., Tuna, M. E., & Çoruh, T. (1991). Güneydoğu Anadolu Kampaniyen-Paleosen otokton istifinin stratigrafisi. TPAO Arama Grubu Raporu, (2414).

Hwang, J. I., Lee, S. E., & Kim, J. E. (2015). Plant uptake and distribution of endosulfan and its sulfate metabolite persisted in soil. PloS one, 10(11), e0141728. https://doi.org/10.1371/journal.pone.0141728.

ISRM, I. (1978). Suggested methods for the quantitative description of discontinuities in rock masses. Int J Rock Mech Min Sci Geomech Abstr, 15(6), 319-368.

Kahraman, S. (2001). A correlation between P-wave velocity, number of joints and Schmidt hammer rebound number. International Journal of Rock Mechanics and Mining Sciences, 38(5), 729-733. https://doi.org/10.1016/S1365-1609(01)00034-X

Karslı, H., Babacan, A. E., Şenkaya, M., & Gelişli, K. (2021). P-ve S-dalga hızları ile jeolojik birimlerin sökülebilirliği üzerine bir değerlendirme. Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, 27(3), 410-419. https://doi.org/10.5505/pajes.2020.35920

Keçeli, A. (2010). Sismik yöntem ile zemin taşıma kapasitesi ve oturmasının saptanması. *Uygulamalı Yerbilimleri Dergisi*, *9*(1), 23-41.

Keçeli, A. (2012). Uygulamalı Jeofizik, JFMO Eğitim Yayınları No.18, 2. Baskı, Ankara.

Khandelwal, M. (2013). Correlating P-wave velocity with the physico-mechanical properties of different rocks. Pure and Applied Geophysics, 170(4), 507-514. https://doi.org/10.1007/s00024-012-0556-7

McCann, D. M., Culshaw, M. G., & Northmore, K. J. (1990). Rock mass assessment from seismic measurements. Geological Society, London, Engineering Geology Special Publications, 6(1), 257-266. https://doi.org/10.1144/GSL.ENG.1990.006.01.28

McDowell, P. W. (1993). Seismic investigation for rock engineering. In Rock Testing and Site Characterization (pp. 619-634). Pergamon. https://doi.org/10.1016/B978-0-08-042066-0.50031-8

Nourani, M. H., Moghadder, M. T., & Safari, M. (2017). Classification and assessment of rock mass parameters in Choghart iron mine using P-wave velocity. Journal of Rock Mechanics and Geotechnical Engineering, 9(2), 318-328. https://doi.org/10.1016/j.jrmge.2016.11.006

Schuenemeyer, J. H., & Drew, L. J. (2011). Statistics for earth and environmental scientists. John Wiley & Sons.

Sharma, P. K., & Singh, T. N. (2008). A correlation between P-wave velocity, impact strength index, slake durability index and uniaxial compressive strength. Bulletin of Engineering Geology and the Environment, 67(1), 17-22. https://doi.org/10.1007/s10064-007-0109-y

Sjøgren, B., Øfsthus, A., & Sandberg, J. (1979). Seismic classification of rock mass qualities. Geophysical prospecting, 27(2), 409-442.

Spearman, C. S. (1904). The proof and measurement of association between two things. American Journal of Psychology, 15, 72-101.

Şaroğlu, F., & Emre, Ö. (1987). Karacadağ volkanitlerinin genel özellikleri ve Güneydoğu Anadolu otoktonundaki yeri. Türkiye, 7, 384-391.

TBEC. (2018). Turkish Building Earthquake Code; T.C. Resmi Gazete: Ankara, Turkey. https://www.resmigazete.gov.tr/eskiler/2018/03/20180318M1-2.htm

Tunç, G., & Alpaslan, N. (2025). Evaluation of the soil of Şırnak (Turkiye) by geotechnical SPT blow counts (SPT-N) with statistical approaches using electrical resistivity tomography (ERT) and shear wave velocity (Vs). Acta Geophysica, 1-27. https://doi.org/10.1007/s11600-025-01683-6

Turhan, N., Balcı, V., & Günay, Y. (2002). Diyarbakır sheet of the Geological Map of Turkey, 1: 500,000 scale. General Directorate of Mineral Research and Exploration, Ankara.

Walford, N. (2025). Practical statistics for geographers and earth scientists. John Wiley & Sons.

Yagiz, S. (2011). P-wave velocity test for assessment of geotechnical properties of some rock materials. Bulletin of Materials Science, 34(4), 947-953. https://doi.org/10.1007/s12034-011-0220-3