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EVALUATION OF MECHANICAL AND ENGINEERING PROPERTIES OF VOLCANIC ROCKS

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Original scientific paper
In order to determine the mechanical and engineering properties of volcanic rocks located in the Armutlu Peninsula, ten samples were collected from various locations in the investigation area and subjected to laboratory tests. Their uniaxial compressive strength (*UCS*), point load strength $Is_{(50)}$, ultrasonic pulse velocity (*UPV*) and density (*d*) were determined. Later statistical correlations were conducted by regression analysis to evaluate relationships between *UPV* and *UCS*, $Is_{(50)}$ and (*d*). The engineering properties of core samples such as brittleness (*B*), fracture toughness (*FT*) and drillability index (*DI*), were determined using *UCS*. The hardness (Schmidt's Rebound Number) was determined using Schmidt hammer and correlated with *UPV*. In addition, the abrasion loss of the volcanic samples was determined. Very significant relations were obtained between *UPV* and mechanical and engineering properties of the volcanic rocks. Seismic refraction and resistivity methods were applied to figure out the dynamic properties of volcanic rocks.

Keywords: *mechanical i physical properties; seismic; volcanic rocks*

Procjena mehaničkih i tehničkih svojstava vulkanskih stijena

Izvorni znanstveni članak
Kako bi se odredila mehanička i tehnička svojstva vulkanskih stijena u poluotoku Armutlu, prikupljeno je deset uzoraka s raznih lokacija na istraživanom području i laboratorijski ispitivano. Određena je njihova jednoosna tlačna čvrstoća (*UCS*), čvrstoća u točki opterećenja $Is_{(50)}$, ultrazvučna brzina impulsa (*UPV*) i gustoća (*d*). Kasnije su statističke korelacije provedene regresijskom analizom kako bi se odredili odnosi između *UPV* i *UCS*, $Is_{(50)}$ i (*d*). Tehnička svojstva kao što su lomljivost (*B*), lomna žilavost (*FT*) te indeks bušenja (*DI*) određeni su primjenom *UCS*. Tvrdoća (Schmidt's Rebound Number) je određena pomoću Schmidt čekića i dovedena u korelaciju s *UPV*. Pored toga određen je gubitak zbog abrazije uzoraka vulkanske stijene. Dobiveni su vrlo značajni odnosi između *UPV* te mehaničkih i tehničkih svojstava vulkanskih stijena. Primijenjene su metode seizmičke refrakcije i otpornosti da bi se izračunala dinamička svojstva vulkanskih stijena.

Ključne riječi: *mehanička i fizička svojstva; seizmički; vulkanske stijene*

1 Introduction

The volcanic rocks in the Armutlu peninsula were studied using geophysical and geotechnical methods. The studies have been limited to massive, easily characterized and strong rocks. This paper focuses on the characterization of volcanic rocks. The specimens were gathered from the host rock-mass for laboratory tests to provide key data to evaluate the performance of the engineered structure during construction and operation phases. This included geotechnical and geophysical measurements on the volcanic rock specimens. The results presented are dry density, uniaxial compressive strength, point load strength, brittleness, sonic velocity, fracture toughness, drillability, and Schmidt hardness [1÷4].

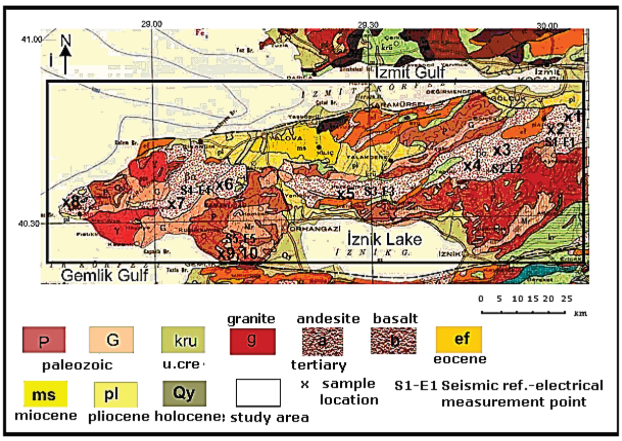

Figure 1 Generalized geological map of the Armutlu Peninsula [6]

The data from the laboratory tests obtained in this paper have been analysed for a series of relationships between the parameters including density, uniaxial compressive strength, point load strength and sonic velocity [1]. The paper presents a number of bivariate plots and relationships for the laboratory dry density and sonic velocity, uniaxial compressive strength and sonic velocity, point load strength and sonic velocity, brittleness and sonic velocity, fracture toughness and sonic velocity, drillability and sonic velocity, and Schmidt hardness and sonic velocity.

2 Geological setting

Recent studies on the Armutlu Peninsula have revealed that the region may be divided into three geological different zones as northern, central and southern [5]. Paleozoic aged gneiss, schists, marble and other metamorphic rocks outcrop southeast and south of the peninsula. Upper Cretaceous aged rocks, mainly carbonates, outcrop southeast and central area of the study area. The Middle Eocene volcanic rocks are widespread in all the three zones. The volcanic rocks are exposed preferentially along the E-W direction, which were formed during the Tertiary. These volcanic rocks intercalate with the shallow marine clastic rocks and carbonates. The volcanic rocks are mainly composed of the andesitic lavas and associated with pyroclastic rocks. In addition to these, lavas of varying petrological range, include basalt, basaltic andesite, dacite and riodacite. In the study area, the andesites occur as lava flows, which alternate with ash and block tuffs and the ash-fall tuffs of intermediate composition. The basic rock occurs in both of lava flows and dykes which cut the andesite. Felsic volcanic rocks occur as small domes (Fig. 1 and Fig. 2).

Figure 2 Andesites exposed in the study area

3 Experimental testing

3.1 Mechanical and physical characterization

The mechanical characterization of volcanics aimed at obtaining the complete behaviour of different types of volcanics under tensile and compressive loading, thus achieving an overview of relevant engineering properties, namely modulus of elasticity, compressive and tensile strength and fracture properties. Ten volcanic specimens (1 riolite, 2 diabase, 1 andesitic basalt, 1 andesite and 5 basalt) were collected from different locations of volcanic area in the Armutlu Peninsula. The specimens used for the investigation are 54 mm diameter and 110 mm long cylindrical samples, which would be acceptable for ASTM [7÷10], or ISRM [11, 12]. In the preparation of the specimens, special care was taken to ensure parallel ends and perpendicular to the longitudinal axis. In addition, the specimen ends were suitably ground so that a smooth surface could be obtained. The rock strength index was obtained using the point load test [9]: The tensile strength of the test samples was determined by closed loop hydraulically operated UTEST testing machine of 200 t capacity. Ultrasonic Pulse Velocity (UPV) measurements of compressional waves (P-waves) were conducted using DT Qust-120+ ultrasonic pulse generator instrument with the transducers having a 54 kHz frequency. P-wave velocities were measured on specimens with a diameter of 54 mm and a length of 110÷115 mm. The density of each core sample was measured after the removal of moisture from it. The Los Angeles abrasion tests were carried out in accordance with ASTM Method C 131-66 ([13, 14]) using course aggregates obtained from hand crushing using a hammer in Armutlu volcanic rock sites. Test samples were oven-dried at 105÷110 °C for 24 h and then cooled at room temperature before they were tested. Grading D was used in the tests. The density of dry samples was obtained from the ratio of mass of samples to their volumes.

2 Estimation of engineering properties

The engineering properties of samples such as brittleness (*B*), fracture toughness (*FT*), drillability index (*DI*) and Schmidt Rebound Number were determined using the following equations [4].

$$B = \frac{UCS \times \sigma_T}{2}, \tag{1}$$

where *B* is brittleness; σ_T is tensile strength (MPa).

$$FT = 0{,}11 \times B^{0{,}43}, \tag{2}$$

where *FT* is the fracture toughness.

$$DI = 0{,}6344 \times B^{0{,}6186}, \tag{3}$$

where *DI* is the drillability.

The brittleness of core samples varies between 34,47 and 206,05 (Tab. 1). There is a good linear relationship between brittleness and UPV. Brittleness increases with increase in *UPV*. The fracture toughness of the samples ranges between 0,50 MPa·m^{0,5} and 1,11 MPa·m^{0,5}. The drillability of the cylindrical cores varies from 5,66 kN/mm to 17,63 kN/mm. Hardness of the core samples was determined using N-type Schmidt hammer with impact energy of 2207 N·m. The Schmidt hardness of the cylindrical cores varies from 35,2 to 51,8.

The empirical relationships between mechanical and engineering properties and *UPV* are given in Tab. 1.

Table 1 Empirical relationships for core samples

$\rho = 0{,}0002 \cdot UPV + 1{,}2447$	$R^2 = 0{,}91$
$UCS = 0{,}0192 \cdot UPV - 47{,}806$	$R^2 = 0{,}80$
$Is_{(50)} = 0{,}0023 \cdot UPV + 7{,}0387$	$R^2 = 0{,}84$
$TS = 0{,}0019 \cdot UPV - 4{,}6009$	$R^2 = 0{,}76$
$TS = 0{,}0981 \cdot UCS - 0{,}0436$	$R^2 = 0{,}97$
$B = 0{,}0919 \cdot UPV - 339{,}34$	$R^2 = 0{,}80$
$FT = 0{,}0003 \cdot \mathrm{UPV} - 0{,}5987$	$R^2 = 0{,}78$
$DI = 0{,}0058 \cdot UPV - 17{,}151$	$R^2 = 0{,}79$
$RN = 0{,}0065 \cdot UPV + 13{,}135$	$R^2 = 0{,}67$
$UCS = 8{,}1065 \cdot Is_{(50)} - 13{,}115$	$R^2 = 0{,}88$

Where ρ - Density, *UPV* - Ultrasonic pulse velocity, *UCS* - Uniaxial compressive strength, $Is_{(50)}$ - Point load index, *B* - Brittleness, *RN* - Schmidt rebound number, *FT* - Fracture toughness, *DI* - Drillability, *TS* - Tensile strength.

Table 2 Dynamic properties of the volcanic rocks

	Symbol	Unit	1. layer
P-velocity	V_P	m/s	365
S-velocity	V_S	m/s	170
Depth	h	m	1,0
Density	ρ	g/cm^3	1,67
Poisson ratio	ν	-	0,36
Shear modulus	G	kg/cm^2	483
Elasticity modulus	E	kg/cm^2	1317
Bulk modulus	k	kg/cm^3	1584
Dominant period	T_o	s	-
Bearing capacity	q	kg/cm^2	1,33

3 Dynamic properties of the volcanic rocks

Dynamic properties of the volcanic rocks were determined applying seismic refraction studies at 5 points of the investigation area by a 12 channel (Ch) Geometrics Seismic Enhancement (Smart Seis) seismograph. Compressional P-wave velocity data were recorded using an in-line spread of 14 Hz, vertical component geophones spaced at 2,0 m intervals. P-wave energy was stacked together from 7 impacts generated by vertically striking a steel plate with an 8 kg sledge hammer. Shear wave data were recorded with the same seismograph using an in-line spread of 14 Hz horizontal component geophones spaced 2,0 m apart and oriented perpendicular to the profile direction. The S-wave seismic source consisted of wooden timber (15×15×200 cm) with steel caps placed on soil beneath the wheels of the vehicle at right angles to the direction of the profile. The P and S- wave velocities and other dynamic properties of the layers are given in Tab. 2.

4 Electrical studies

The importance of electrical survey is to determine the subsurface resistivity distribution by conducting measurements on the ground surface. From these measurements, the apparent resistivity of underground can be estimated. The ground resistivity is related to various geological parameters such as porosity and degree of water saturation, and the mineral and fluid content

In order to determine the resistivity values of the volcanic rocks, Vertical Electrical sounding (VES) was applied at 5 points at the investigation area using Schlumberger configuration.

Three layers were determined. The average resistivity and thickness of the layers are ρ_1 = 1140 Ωm, h_1 = 0,8 m, ρ_2 = 4600 Ωm, h_2 = 5,4 m. The resistivity of the 3rd layer is ρ_3 = 5400 Ωm. The high resistivity value (ρ_1 = 1140 Ωm) is associated with disintegrated basalt at the surface and higher resistivity values (4600 Ωm and 5400 Ωm) are associated with the harder section of basalts beneath the disintegrated layer.

5 Results

The mechanical and engineering properties of volcanic rocks in the Armutlu peninsula have been determined by applying laboratory tests, using empirical equations and in situ geophysical studies, and the allowing results were obtained.

a) The laboratory experiments were performed over rock samples, geophysical seismic velocity measurements and electrical sounding (resistivity) applications were performed in-situ over the volcanic rocks.
b) The volcanic rocks exposed preferentially along the E-W direction were formed during the Tertiary intercalate with the shallow marine clastic rocks and carbonates which are mainly composed of the andesitic lavas and associated with pyroclastic rocks.
c) Three seismic layers were found with the following P velocities: V_{P1} = 365 m/s, V_{S1} = 170 m/s, V_{P2} = 1850 m/s, V_{S2} = 960 m/s, V_{P3} = 4560 m/s and V_{S3} = 2350 m/s. The two upper layers are composed of basalts while the third is massif basalt.
d) The density of the volcanic rocks varies between 2,1 g/cm^3 and 2,52 g/cm^3. The *UPV* ranges from 4125 m/s to 6163,5 m/s whereas the *UCS* varies between 27,8 MPa and 63,4 MPa. The $Is_{(50)}$ ranges from 2,18 MPa to 6,48 MPa, and tensile strength σ_T varies between 2,47 MPa and 6,5 MPa.
e) It is shown that UPV is closely related to uniaxial compressive strength, point load index, drillability, fracture toughness and Schmidt rebound number.
f) Three layers were distinguished in resistivity studies. Based on the observation from the surface geology the 0.8 cm thick first layer belongs to composed by weathered and altered rock (ρ_1 = 1140 Ωm); The 5,4 cm thick second layer (4600 Ωm) and the third layer (5400 Ωm) are associated with the harder section of basalts.
g) The average abrasion loss values of the volcanic rocks in the Armutlu peninsula is 13,39.

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