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RESEARCH ARTICLE

THE EFFECT of ANISOTROPY on the DYNAMIC PROPERTIES of SCHIST ROCKS

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ABSTRACT

Dynamic elastic properties of rocks such as modulus of elasticity and Poisson's ratio are important in some design stages of underground and surface engineering structures. Also, anisotropy is that rocks show different strength and deformation properties with the different orientation angles that they gain as a result of the effect of the direction, fabric, microstructure and discontinuities. Different lithological rock units with anisotropy characteristics are encountered in studies carried out in underground and surface engineering structures, and in cases with such characteristics, there are problems in terms of stability.

In this study, the effect of the anisotropic property of rock masses on elastic parameters such as dynamic young modulus and dynamic Poisson's ratio were investigated. For this purpose; samples with different orientations were obtained from schists, which are metamorphic rocks, at 0°, 15°, 30°, 45°, 60°, 75° and 90°. Experimental studies were carried out to determine the mechanical and physical properties of these samples. Dynamic young modulus and dynamic Poisson's ratio were determined by P and S velocity of wave propagation experiments. With the results obtained, while the young modulus and Poisson's ratio of samples belonging to the green schist rock unit with different orientations show a relatively stable structure, these values for the mica schist unit are quite variable and wavy. Therefore, the anisotropy feature of the rock must be taken into consideration in terms of the stability of the structure in engineering studies to be carried out in the mica schist unit.

Keywords: *Anisotropy, P and S wave, Rock dynamic properties*

1. INTRODUCTION

Anisotropy in rocks is the fact that rocks show different strength and deformation properties in different orientations and bedding. Different researchers have studied the strength and deformation changes of anisotropic rocks. [1–5]. It was determined that these values increased in the direction perpendicular to the bedding and decreased in the direction parallel to the bedding. However, these values may vary depending on the rock type.

P and S wave values are used to detect structures such as voids, discontinuities and cracks in the rock and concrete samples, and to find the dynamic modulus of elasticity and dynamic Poisson's ratios. [6]. The ultrasonic sound velocity experiment is not generally applied to anisotropic rocks. It is more suitable for rocks of low anisotropy levels [7].

Wang and Li [8] obtained P wave velocity increase at 0° and close values for S wave velocity in shale samples taken at 0°, 15°, 30°, 45°, 60°, 75° and 90°. This situation is explained by the fracture morphology obtained by computer tomography. It is thought that the excess in the number of voids and cracks increase these values.

Ribacchi et al. [9] applied P wave propagation velocity test at 0°, 45° and 90° in dried and saturated media to examine the schistosity structure of gneiss rock. It was stated that an increase was observed in the values in the saturated medium compared to the dry ones. It was mentioned that the values were close to each other in the saturated environment and there were differences in the dried media. It was stated that the values for both media are maximum at 90° and these observations were caused by the differences in bedding, void and crack structures in the rocks.

Khandelwal and Sing [10] reported that uniaxial compressive strength, tensile strength, density, Young's modulus and Poisson's ratio values were highly correlated with P wave velocity values in their experiments on coal, shale and sandstone samples, which are layered and anisotropic rocks.

Kim et al. [11], investigated the P wave velocity changes of gneiss, schist and shale samples at 0°, 15°, 30°, 45°, 60°, 75° and 90°. Maximum wave velocities were obtained at 90° and minimum wave velocities at 0°. It was stated that the stratified structure was effective in these values.

Ali et al. [12] studied the anisotropic behaviour of the banded amphibolite rock. Uniaxial and triaxial compressive strength and P-S wave propagation velocity tests were performed on the cores prepared at 0°, 30°, 60° and 90°. P and S wave velocity values in the direction parallel to the foliation plane (0°) were higher than that perpendicular (90°). The reason for this was stated as the excess of quartz and hornblende in these planes.

Huang et al. [13] tried to determine the fracture behaviour of coals with acoustic emission tests in the direction perpendicular and parallel to the bedding. By applying lateral pressures between 0-40 MPa, dynamic deformations were tried to be obtained by trying to create underground strength conditions with P and S ultrasonic wave velocity experiments. Acoustic emission rates perpendicular and parallel to the stratification gave different values. It was stated that maximum acoustic emission values were obtained especially in saturated coal samples. It was emphasized that water affected the fracture maximally. In addition, it was remarked that the dynamic deformation parameters (dynamic modulus of elasticity and dynamic Poisson's ratio) decreased with different lateral pressures. It was mentioned that lateral pressure had an opposite effect on dynamic deformations.

In this study, ultrasonic sound velocity tests were carried out on cores taken from green schist and mica schist rocks with anisotropic structures at 0°, 15°, 30°, 45°, 60°, 75° and 90°. The variation of P and S wave velocities, dynamic modulus of elasticity and dynamic Poisson's ratios were investigated. This study focused on the dynamic properties of anisotropic schist rocks due to their stratified structure, which can cause different values in different bedding orientations.

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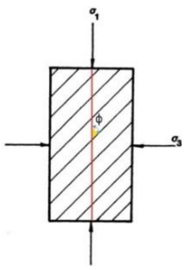
2. MATERIAL

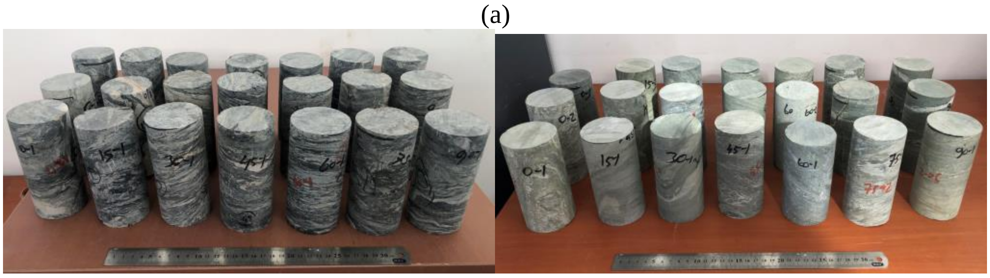
The block and core samples used in this study were obtained from the copper field of the Hanönü district of Kastamonu, Turkey. The ore production in the field, which belongs to the private sector, is carried out by the open pit method (Fig. 1).

Figure 1. Researh site location.

In the study, both drilling samples made by the enterprise and samples obtained from the blocks were used. Experimental studies were carried out at 0°, 15°, 30°, 45°, 60°, 75° and 90° on HQ diameter (63.5 mm) anisotropic samples (Fig.2 b,c). In Figure 2 (a), the degree (ϕ) system determined according to the loading axis is indicated.



(a)



(b) (c)

Figure 2. a. Core anisotropy (ϕ: degree), b. mica schist, c. green schist.

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The samples were separated at the specified degrees and the experiments were carried out in dried and saturated environments. To determine the physical properties of the samples, density, water absorption rate by weight and volume, porosity and void ratio experiments were carried out. Ultrasonic sound velocity tests were applied to the samples at 0°, 15°, 30°, 45°, 60°, 75° and 90° in dried and saturated conditions. To determine the mineralogical and petrographic properties of the rocks, X-Ray diffractometry (XRD) and X-Ray fluorescence (XRF) tests were performed at the Advanced Technologies Center of Kütahya Dumlupınar University.

2.1. Kastamonu-Hanönü Geology

Stratigraphical section of the Akgöl Formation, Çağlayan Formation, Kapanboğazı Formation, Yemişliçay Formation, Gürsökü Formation and Akveren Formation observed in and around the mine site is given in Figure 3 [14]. The study area is in Akgöl formation and it contains medium-thick bedded, coarse pebble-block conglomerate, marble lenses, green-coloured, medium-thick bedded schist, black coloured, thin-medium-thick bedded schist and massive sulphide mineralization structures. The mine site is surrounded by Volcanogenic Massive Sulphite (VMS) type mineralizations associated with the Triassic-Jurassic Akgöl Formation along Taşköprü-Hanönü of Kastamonu province and mineral deposits associated with the Çangaldağ complex rocks [14,15].

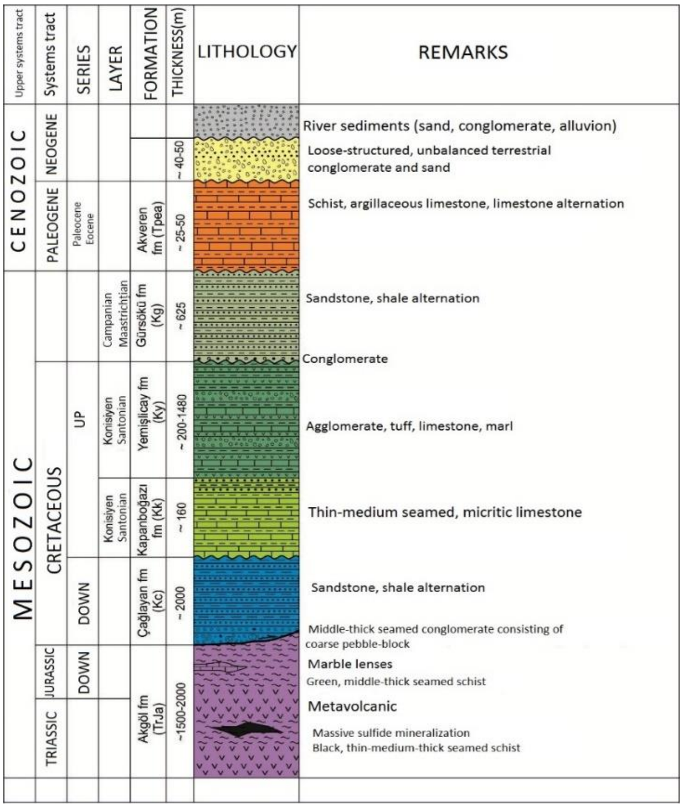

Figure 3. Stratigraphical section of the work area [14].

3. EXPERIMENTAL STUDIES

3.1. Physical Properties

Green schist and mica schist cores at 0°, 15°, 30°, 45°, 60°, 75° and 90° were dried in an oven at 105°C for 24 hours and then cooled in a desiccator for 30 minutes according to the method suggested by ISRM [7]. They were kept in distilled water until they became saturated. The physical properties obtained for both rocks are presented in Table 1.

Table 1. Physciacal properties of green schist and mica schist.

Samples	**Dry Density (gr/cm^3)**	**Saturated Density (gr/cm^3)**	**Water Absorption by Weight (%)**	**Water Absorption by Volume (%)**	**Porosity(%)**	**Void Ratio**
Green Schist	2,79	2,80	0,18	0,54	0,537	0,0054
Mica Schist	2,70	2,74	1,20	3,22	3,223	0,0336

According to Table 1, since mica schist has water absorption values of 1,20% and 3,22% by weight and volume, respectively, and green schist has water absorption values of 0,18% and 0,54% by weight and volume, it is understood that mica schist has more voided or porous structure.

3.2. Mineralogical and Chemical Analysis

XRD and XRF analyzes were performed to determine its mineralogy and chemical properties. For green schist; muscovite, albite, orthoclase, kaolinite and quartz minerals peaked. Albite and orthoclase were were found in higher numbers for green schist than for other minerals. In the XRD of mica schist, muscovite, clinochlore (chlorite type), albite, kaolinite and quartz minerals peaked (Figures 4 and 5). Major oxide results of green schist and mica schist units are given in Table 2. According to these results; especially SiO_2 was more than 40% in both units.

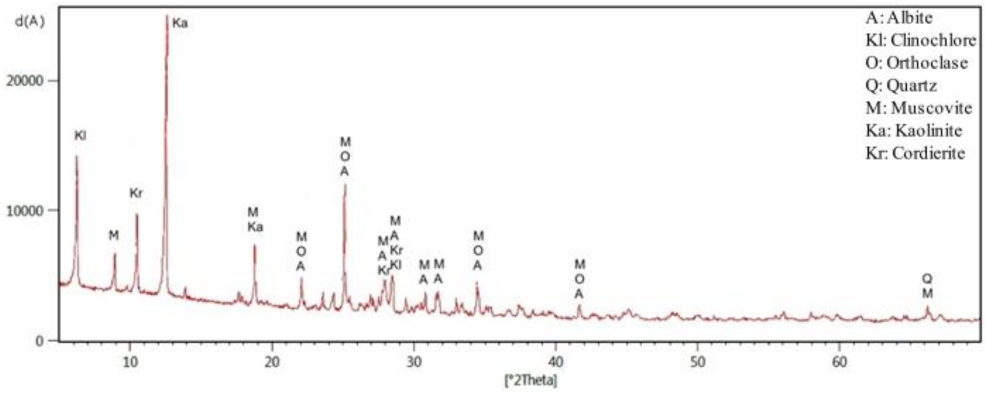

Figure 4. Green schist XRD analysis results.

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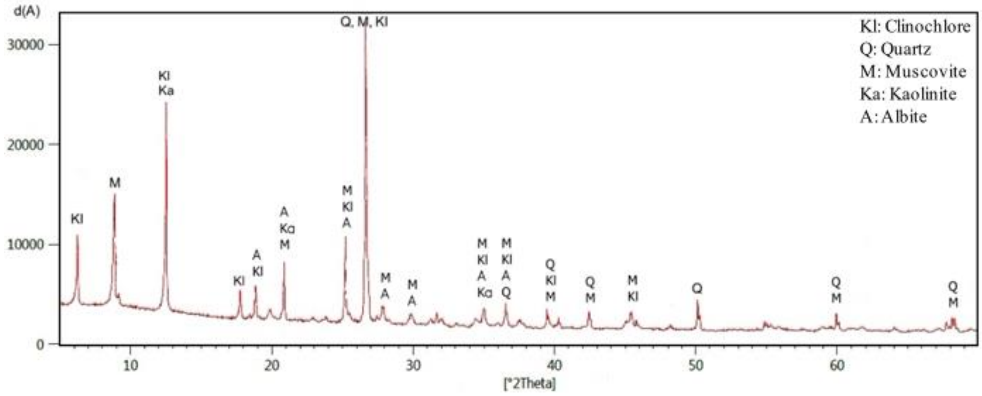

Figure 5. Mica schist XRD analysis results.

Table 2. Green and mica schist XRF results.

Sample	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**K_2O**	**MgO**	**CaO**	**Na_2O**	**TiO_2**	**P_2O_5**	**MnO**	**LOI**
Mica Schist	50,11	23,07	9,87	4,45	2,58	1,68	0,92	0,85	0,78	0,95	4,82
Green Schist	40,33	14,26	15,94	0,96	10,71	9,73	1,78	1,67	0,14	0,27	4,19

3.3. Uniaxial Compressive Strength Tests

Green schist and mica schist cores at 0°, 15°, 30°, 45°, 60°, 75° and 90° were obtained according to the method suggested by ISRM [7] with a ratio of 2-2,5 L/D (L: Length, D: Diameter). Experiments were carried out in dry and saturated conditions. 10 core samples were used for each orientation angle in experiments.

According to uniaxial compression test results (Figure 6); In terms of strength values in dry and saturated conditions, in general, minimum results were obtained between 30° and 60°, maximum 0° and 90° for mica schist, minimum between 15°-30° and maximum between 60°-75° for green schist. It has been observed that the mica schist unit is highly affected by water.

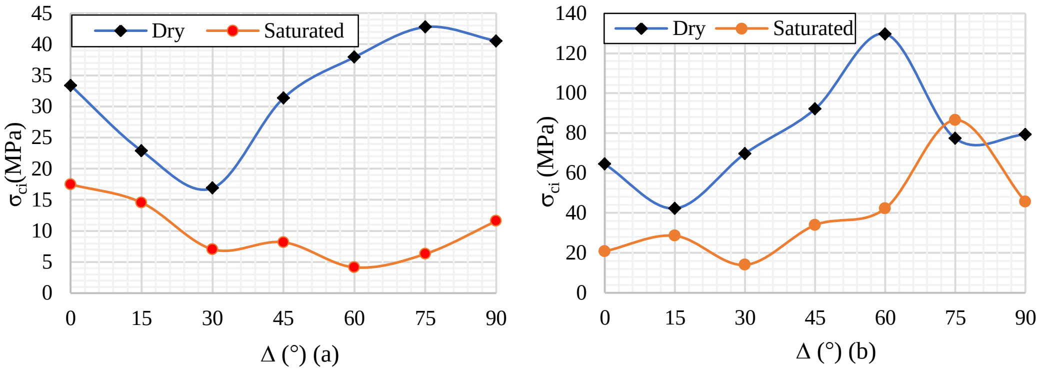

Figure 6. Dry and saturated uniaxial compressive strength values of mica schist (a) and green schist (b) (Δ (°)=Anisotropic angles) [16,17].

3.4. Ultrasonic Sound Velocity Experiments (P and S Waves)

Green schist and mica schist cores at 0°, 15°, 30°, 45°, 60°, 75° and 90° were obtained according to the method proposed by ISRM [7] with a ratio of 2-2,5 L/D (L: Length, D: Diameter). Experiments were carried out in dry and saturated conditions. 10 core samples were used for each orientation angle in experiments.

Within the scope of the study, the Proceq brand Pundit Lab+ device was used. Separate transducers were used for P and S waves. Apparatus with a frequency of 54 kHz for the P wave and 40 kHz for the S wave were used (Figure 7, 8).

Figure 7. P wave experiment set-up.

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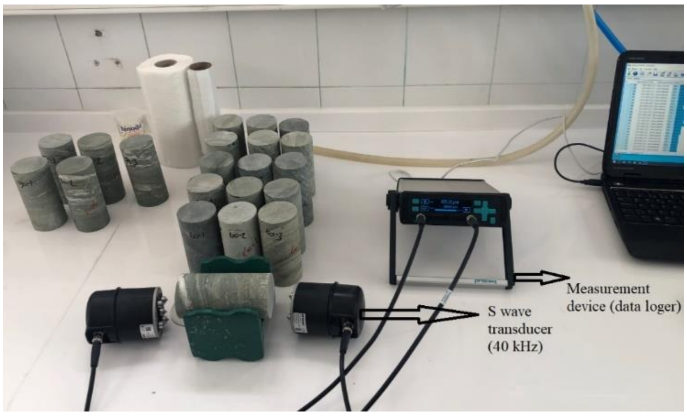

Figure 8. S wave experiment set-up.

Parameters in Table 3 are used to make measurements in P and S waves devices.

Table 3. P ve S wave parameters.

Parameters	**P wave**	**S wave**
Probe frequency	54 kHz	40 kHz
Pulse amplitude	auto (500 V)	500 V
Rx probe gain	auto (10x)	500 x
Calibration time	25,4 µs	6,6 µs

In order to find the dynamic modulus of elasticity and dynamic Poisson's ratios, the Equation proposed by ISRM [7] (Eq.1 and 2) were used;

Dynamic Young modulus (Pa): $$E_u = \rho V_s^2 \frac{(3V_p^2 - 4V_s^2)}{(V_p^2 - V_s^2)} \quad (1)$$

Dynamic Poisson's ratio: $$V_{dyn} = \frac{(V_p^2 - 2V_s^2)}{2(V_p^2 - V_s^2)} \quad (2)$$

where;
V_p: P wave velocity (m/s),
V_s: S wave velocity (m/s),
ρ: Rock density (kg/m^3).

The results obtained for green schist and mica schist are presented in Figures 9, 10, 11,12 and Table 4.

Table 4. P ve S wave speed results in dried and saturated conditioned for green schist and mica schist.

Rock Type	**Degrees (◦)**	**Dried Conditioned P Wave Speed (m/sn)**	**Saturated Conditioned P Wave Speed (m/sn)**	**Dried Conditioned S Wave Speed (m/sn)**	**Saturated Conditioned S Wave Speed (m/sn)**
	0	5788,67	5784,33	3820,00	3221,22
	15	6219,11	6137,67	4028,33	3370,78

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Green Schist	30	4609,56	4335,44	3086,89	2330,11
	45	4856,56	4843,44	3369,22	2855,33
	60	4988,33	4875,56	2825,78	2520,78
	75	5106,33	4825,00	3424,00	3427,44
	90	5234,33	4972,67	3457,89	3440,22
Mica Schist	0	4338,11	4027,00	2662,11	2646,00
	15	3174,22	2850,00	2265,56	1770,00
	30	2654,78	1962,00	2217,11	1541,00
	45	1820,22	2304,00	1723,22	1500,00
	60	2764,22	2600,00	2528,00	2292,00
	75	3089,78	2710,00	2451,33	2020,00
	90	2714,00	2558,00	2315,44	1559,00

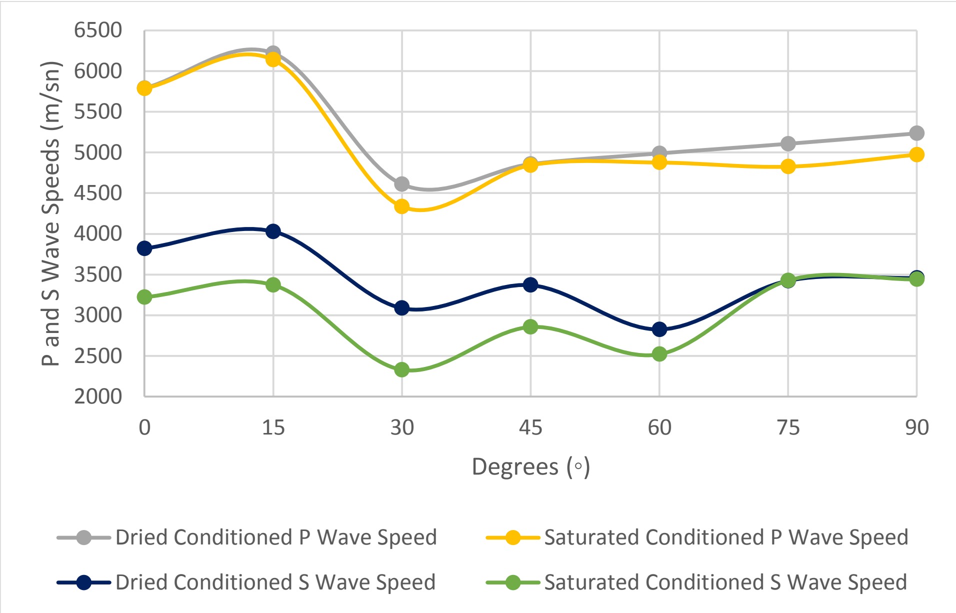

Figure 9. Green schist P and S waves values in dried and saturated conditions.

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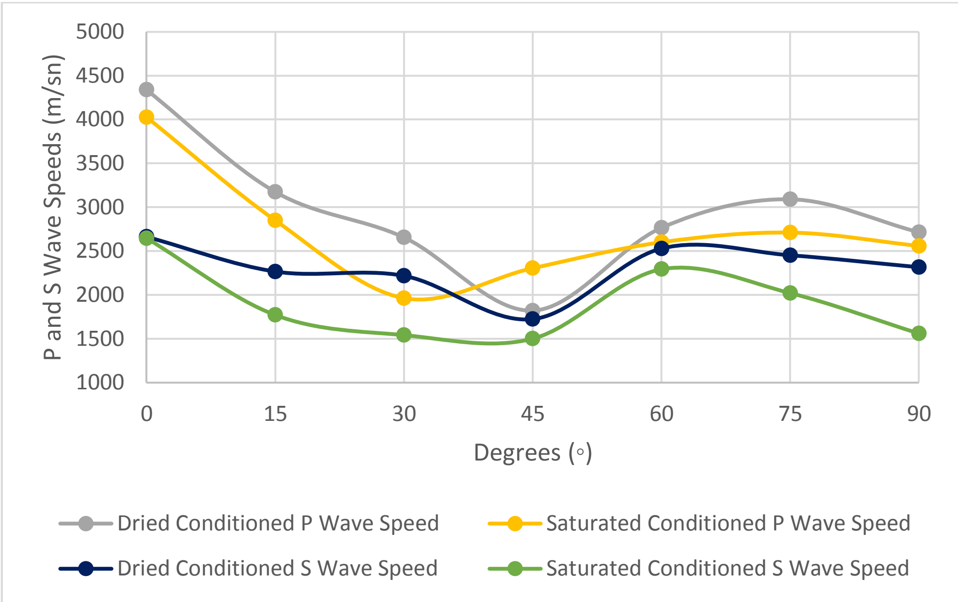

Figure 10. Mica schist P and S waves values in dried and saturated conditions.

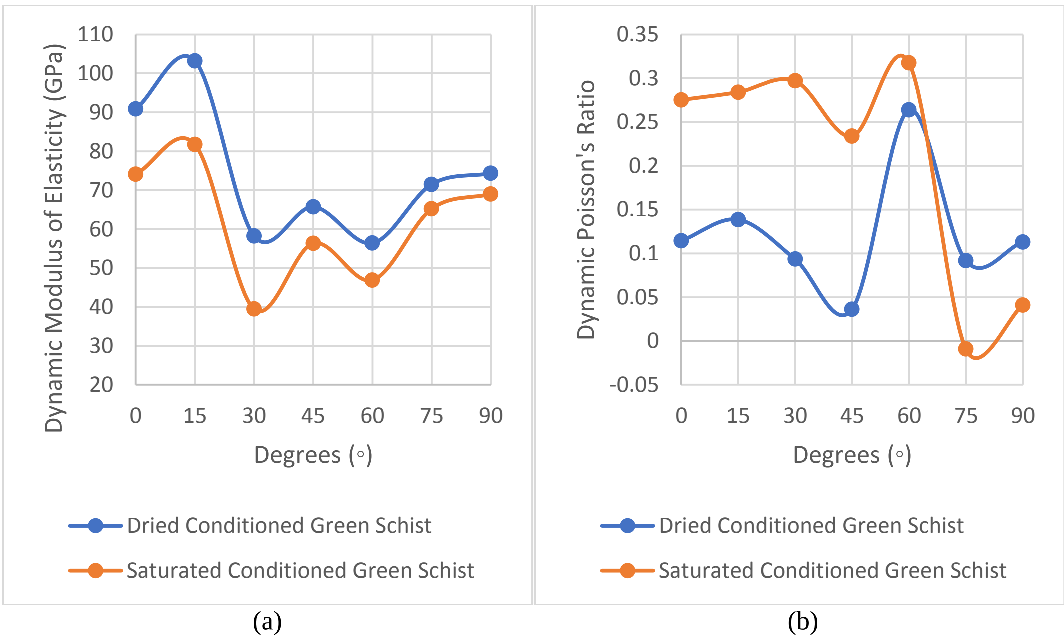

Figure 11. Green schist in dried and saturated conditions, dynamic modulus of elasticity (a) and dynamic Poisson's ratio (b) values.

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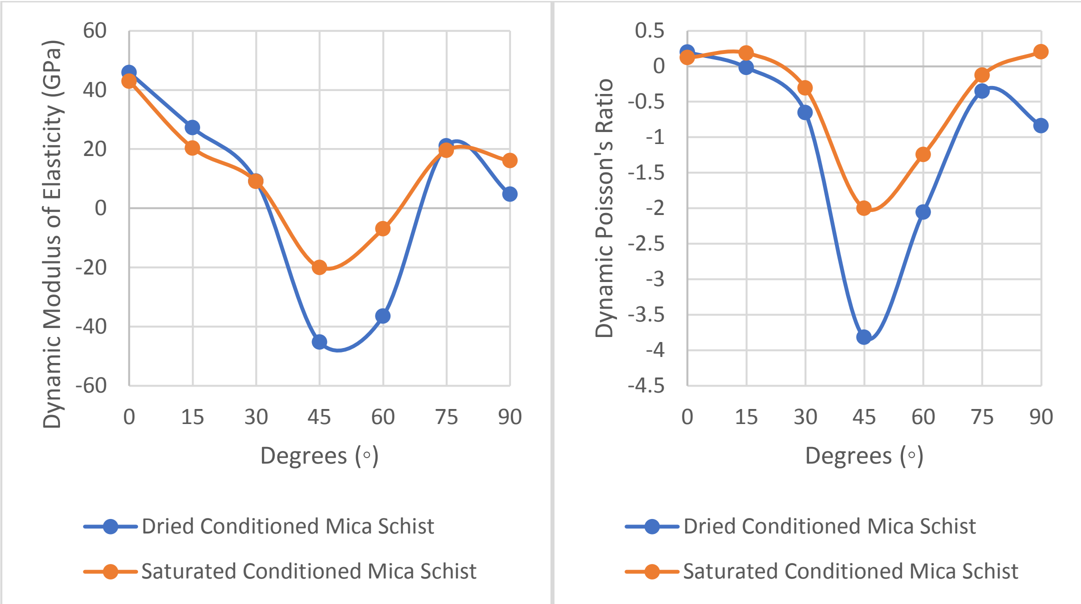

(a) (b)

Figure 12. Mica schist in dried and saturated conditions, dynamic modulus of elasticity (a) and dynamic Poisson's ratio (b) values.

Based on the results of green schist and mica schist samples, P, S wave velocities and dynamic elasticity modulus values in dried and saturated conditions were generally minimum between 30°-60° and maximum results were obtained at 0°. Wave velocities in the saturated medium were lower than in the dried medium. Results close to the distribution of uniaxial compressive strength values based on degrees were obtained. For dynamic Poisson's ratios, values for green schist dried and saturated conditions were obtained at minimum 45° and 75° respectively, and maximum at 60° for both conditions. For mica schist, maximum at 0°, minimum between 45°and 60° results were obtained in both conditions.

4. CONCLUSIONS

Within the scope of this study, physical, mechanical tests, mineralogical and chemical analyzes and ultrasonic sound velocity tests were applied to the samples taken at 0°, 15°, 30°, 45°, 60°, 75° and 90° in dried and saturated conditions.

A certain distribution was observed in terms of wave velocities. The minimum values for both rocks were observed between 30° and 60° in dried and saturated conditions, and the maximum values were observed at 0°. The same distribution trend was found within the dynamic elasticity modulus. It is thought that this is due to the fact that bedding, voids and crack structures are encountered less frequently at 0° while providing wave propagation during the experiment, and that it cuts more into these structures between 30° and 60°. To reveal these structures more clearly, it is recommended to perform acoustic emission and computer tomography tests. In terms of wave propagation velocities, the values in the saturated medium were lower. Water had a negative effect on the results.

Uniaxial compressive strength values gave relatively close values to wave propagation velocities (P and S) and dynamic modulus of elasticity. In terms of dynamic Poisson's ratio values, the maximum values at 60° and 0° for green and mica schist respectively dried and saturated conditions. Minimum values were obtained between 45° and 75° for both rock types.

Mica schist rock gave negative results in dynamic modulus of elasticity and dynamic Poisson's ratio. This is due to the excess of the void and crack in the rock. Therefore, water affects this rock negatively. Also, there are negative results in dried conditioned for mica schist. It is thought that it would be beneficial to take precautions in terms of safety in engineering studies to be carried out in the mica schist rock.

The importance of investigating the distribution of strength and dynamic properties (Poisson’s ratio and dynamic elasticity module) in rocks showing anisotropic structure is emphasized through this study. As a result, it is recommended to consider anisotropy in engineering projects to be carried out.

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