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Araştırma Makalesi / Research Article

Effect of Anisotropy on Basic and Residual Friction Angles in Schist Rocks

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Abstract

The basic friction angle (φ_b) tests are a common and practical method used to determine the shear strength of discontinuities. Tilt device is generally used in basic friction angle experiments. In this study, the effects of the anisotropy properties of green and mica schist rocks taken from the copper mine site in Kastamonu Hanönü district on the basic and residual friction angles were investigated. For this purpose, experiments with a specially designed tilt device were conducted on dried and saturated green schist and mica schist samples with orientation angles of 0°, 15°, 30°, 45°, 60°, 75° and 90° relative to the loading axis. According to the results in dried and saturated conditions, maximum basic and residual friction angle values were obtained for green schist samples at 60°. The results were close to each other in the experiments carried out in both saturated and dried conditions. Green schist samples were less affected by the saturated media. Mica schist samples were not affected by anisotropy for both media, and close values were obtained in all orientation angles. It was determined that the basic and residual friction angles were lower in saturated conditions compared to dried ones.

Keywords
Anisotropy;
Mica Schist;
Tilt Device;
Green Schist

Şist Kayaçlarında Anizotropinin Temel ve Rezidüel Sürtünme Açılarına Etkisi

Öz

Temel sürtünme açısı (φ_b) deneyleri süreksizliklerin kayma dayanımının belirlenmesi için kullanılan yaygın ve pratik bir yöntemdir. Temel sürtünme açısı deneylerinde genel olarak tilt cihazı kullanılmaktadır. Bu çalışmada, Kastamonu Hanönü ilçesindeki bakır madeni sahasından alınan yeşil ve mika şist kayaçlarının anizotropi özelliklerinin temel ve rezidüel sürtünme açılarına etkisi incelenmiştir. Bu amaçla, yükleme eksenine göre 0°, 15°, 30°, 45°, 60°, 75° ve 90° yönelim açısına sahip kuru ve doygun yeşil şist ve mika şist numunelerine özel olarak tasarlanan tilt cihazı ile deneyler uygulanmıştır. Kuru ve doygun ortamlardaki sonuçlara göre yeşil şist numuneleri için 60°de maksimum temel ve rezidüel sürtünme açısı değerleri elde edilmiştir. Hem doygun hem de kuru ortam şartlarında yapılan deneylerde birbirine yakın sonuçlar elde edilmiştir. Doygun ortamdan yeşil şist numuneleri daha az etkilenmiştir. Mika şist numuneleri ise her iki ortam için anizotropiden etkilenmemiş ve tüm yönelim açılarında yakın değerler elde edilmiştir. Doygun ortam şartlarında temel ve rezidüel sürtünme açısının, kuru ortam şartlarına kıyasla daha düşük değerlerde olduğu belirlenmiştir.

Anahtar kelimeler
Anizotropi;
Mika Şist;
Tilt Deneyi;
Yeşil Şist

1. Introduction

Anisotropy is the fact that rocks show different strength and deformation properties based on their orientation angles and bedding planes. In the strength and deformation tests, generally different results are obtained relative to the loading axis (Ramamurthy *et al.* 1993, Nasseri *et al.* 2003, Zhang et al. 2011, Cho *et al.* 2012, Salager *et al.* 2013, Xu *et al.* 2019, Huang *et al.* 2020). Especially in metamorphic rocks, unlike magmatic and sedimentary rocks, mechanically different results may occur in different orientations due to their properties such as bedding, schistosity, foliation, etc. The results of experiments carried out in the perpendicular and parallel direction to stratification may vary (Saroglou and Tsiambaos 2008, Ismael *et al.* 2017, Ajalloeian and Lashkaripour 2000). Therefore, the change of rock properties according to the orientations with the effect of anisotropy shows that it is a parameter that should be kept at the forefront in engineering studies such as in open or underground mining operations. In the studies to be done, the effect of the orientation angle must be determined in terms of the stability of the structure. Discontinuities are geological structural defects that adversely affect the stability of underground and surface engineering constructions. These discontinuities, which occur during or after the formation of rocks in geological time, may have different orientation angles. Basic friction angle tests are a common method used to determine the mechanical rock properties (basic and residual friction angle) of discontinuities in different orientations. Shear strength and friction angle are important internal parameters for the properties of discontinuities. Anisotropy is effective in the different distribution of these properties of discontinuities. Shear strength and friction angles can vary in different orientations and stratifications (Wang *et al.* 2017, 2018).

In basic friction angle tests, besides the effective parameters such as rock surface roughness, rock density, joint strength and tilt test speed, rock anisotropy can be ignored. Generally, in tilt device experiments, the effects of dried, saturated media, two or three cores setups, plate type rocks, lengthwise cut core or plate samples on the basic friction angle were investigated (Alejano *et al.* 2012, González *et al.* 2014, Kim *et al.* 2016, Ulusay and Karakul 2016, Jang *et al.* 2018, Beyhan and Özdemir 2021).

In this study, it was aimed to investigate the anisotropy effect of green schist and mica schist metamorphic rocks taken from the copper mine in Kastamonu Hanönü district on the basic and residual friction angles. Due to the foliated structure of the rocks, cores were taken at different orientation angles (0°, 15°, 30°, 45°, 60°, 75° and 90°) and the changes in friction angles of different orientations were investigated in the three cores set up.

2. Material and Method

2.1 Material

Green schist and mica schist rocks taken from the copper mine located in the Hanönü district of Kastamonu, Turkey, were used in the study. The workplace (red zone) is given in Figure 1.

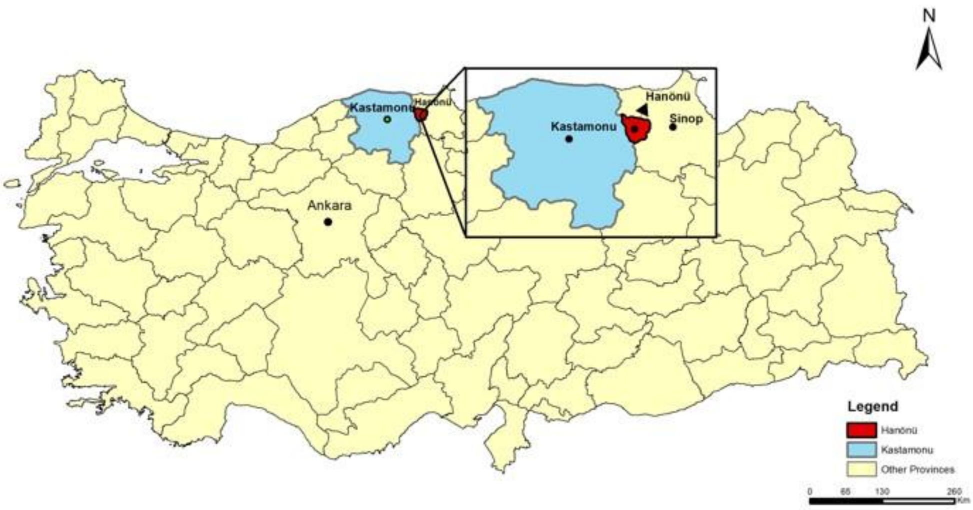

Figure 1. Study area location.

Blocks representing the site were taken from the green schist and mica schist units in the field and HQ diameter (63.5 mm) samples were obtained from these blocks. Also, samples with HQ diameter (63.5 mm) with orientation angles of 0°, 15°, 30°, 45°, 60°, 75° and 90° were taken from field drilling. Samples were prepared with L/D (L: Length, D: Diameter) ratio of 2-2.5. The orientation angles (α) were taken according to the loading axis as in Figure 2, and cores at different angles were obtained.

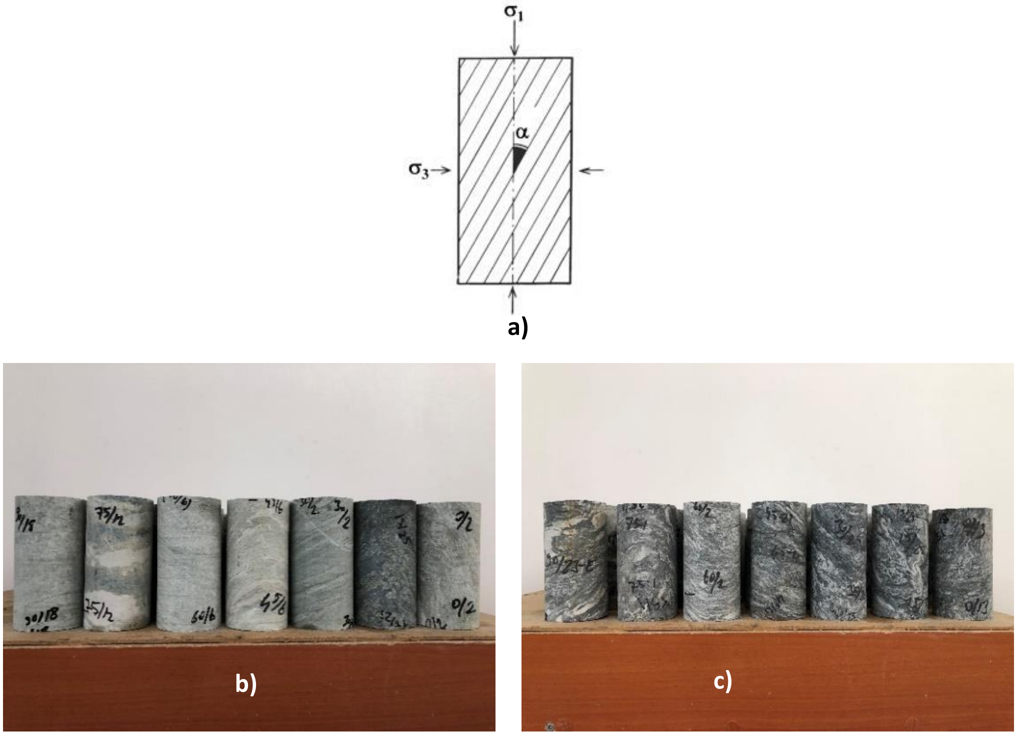

Figure 2. a) Orientation angle (α) b) green schist c) mica schist.

The cores used in the basic friction angle tests were conditioned in dried and saturated medias. The samples were first dried in an oven at 105°C for 24 hours according to the method suggested by ISRM (2007). After that, it was kept in a desiccator and kept in distilled water until it became saturated. The physical and mechanicall properties obtained for both rocks are presented in Table 1.

Table 1. Physical and mechancial properties of green schist and mica schist (Özdemir 2021).

Samples	Dry Density (gr/cm^3)	Saturated Density (gr/cm^3)	Water Absorption by Weight (%)	Water Absorption by Volume (%)	Porosity (%)	Void Ratio	UCS (MPa)	BTS (MPa)
Green Schist	2.79	2.80	0.18	0.54	0.54	0.0054	59.05	13.52
Mica Schist	2.70	2.74	1.20	3.22	3.22	0.0336	25.10	6.10

UCS: Uniaxial compressive strength, BTS: Brazilian tensile strength.

According to the results in Table 1, it is understood that mica schist is more porous or voided than green schist. SEM (Scanning Electron Microscobe) method was performed to examine this porous and surface fabric structure of mica schist (Figure 3). It was observed that the continuity of the porous and fabric structure is less in green schist and more in mica schist. This situation caused the mica schist to be more affected by water. According to the results of UCS and BTS, green schist has higher strengh values than mica schist.

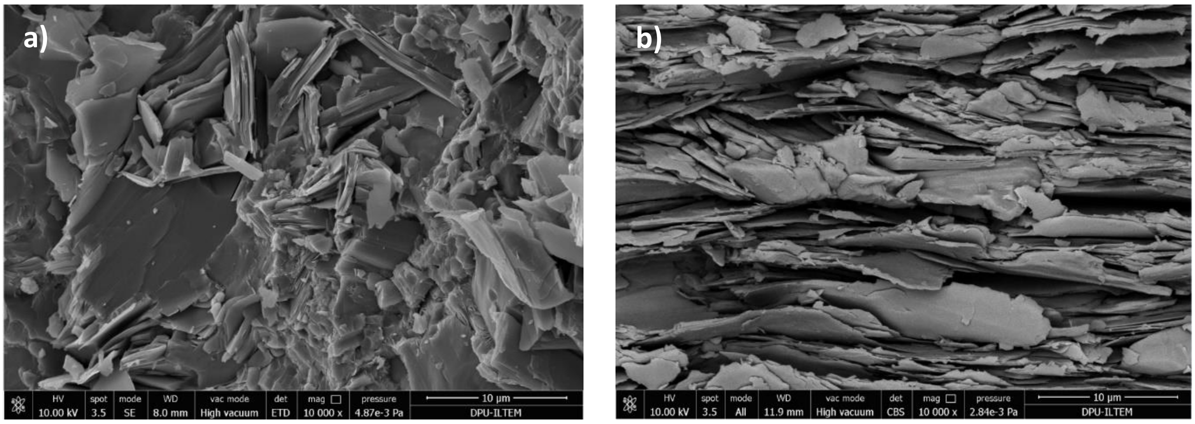

Figure 3. SEM images (a) green schist, (b) mica schist (Özdemir 2021).

2.2 Basic friction angle tests

Basic friction angle experiments was carried out according to the method suggested by Alejano et al. (2018). In addition, the suggestions presented in studies by various researchers (Alejano *et al.* 2012, Ruiz and Li 2014, Ulusay and Karakul 2016, Zhang *et al.* 2018, Tang *et al.* 2020) were also taken into account in the experiments. The tests are generally carried out according to the condition of the cylindrical or prismatic plate-shaped samples. Experiment application types are indicated in Figure 4. During the cutting of the cores, problems were experienced in the lengtwise cuts due to the fractured and cracked state of the mica schist. For this reason, the three cores set up system was chosen (Fig. 4c). The two cores set up system experiments weren't carried out as stability could not be achieved during the experiment (Fig. 4d).

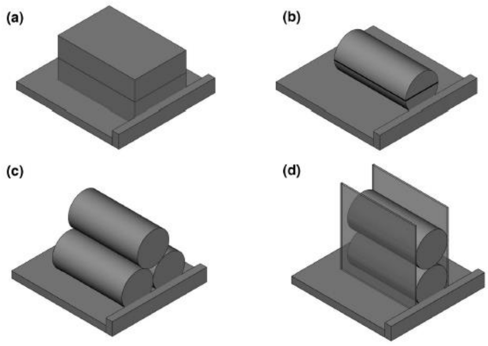

Figure 4. Basic internal friction angle test types (Alejano *et al.* 2018).

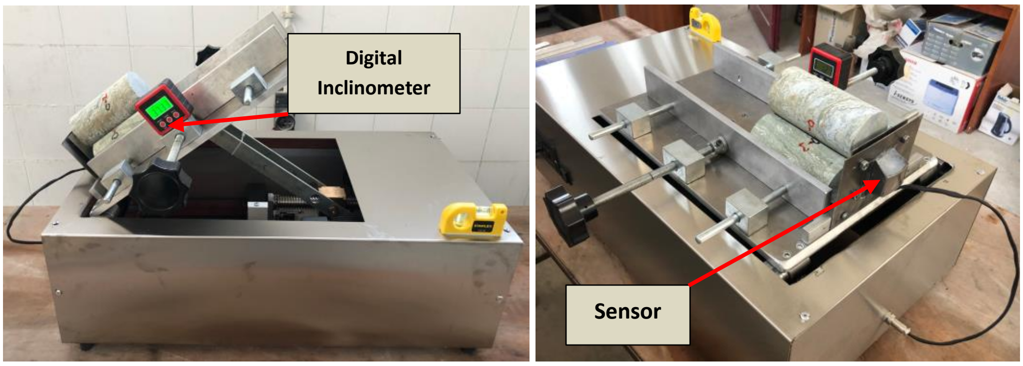

Figure 5. Designed tilt device.

Experiments were carried out with a specially designed tilt device using cores prepared in dried and saturated conditions (Figure 5). The device has 30 × 40 cm inclined plate and varying incline speed (5.2°/min.-21°/min). In this way, vibration is minimized during the experiment and optimum accurate values are reached. In addition, the test device can be stopped through sensor automatically when the sample touches the plate. The device has a digital inclinometer that can measure the slip angle with an accuracy of ±0.1°. Optimum conditions can be achieved by measuring horizontality with a water level measuring tool on the device.

In the Barton-Bandis failure criterion (Barton 2013, 2016, Barton and Bandis 2017), it is possible to switch from the basic friction angle results obtained from the tilt experiments to the residual friction angle values (Equations 1 and 2). In this way, the internal parameters of the discontinuities (friction angle and shear strength) can be obtained.

$$\tau = \sigma_n tan\left[JRC\ log\left(\frac{JCS}{\sigma_n}\right) + \varphi_r\right] \qquad (1)$$

Where τ is the joint shear strength (MPa), σ_n is the normal stress to joint (MPa), φ_r is the residual friction angle (°), JRC is the joint roughness coefficient and JCS is the joint compressive strength (MPa).

$$\varphi_r = (\varphi_b - 20°) + 20\frac{r}{R} \qquad (2)$$

Where φ_b is the basic friction angle (°), φ_r is the residual friction angle (°), r is the Schmidt rebound number for discontinuity, R the Schmidt rebound number for core.

The basic friction angle values were reached by a specially designed tilt device. According to the methods suggested by ISRM (Alejano *et al.,* 2018), 5 measurements were taken for each sample, and their medians were determined (Equation 3). After the measurement, the contact surfaces of the samples are cleaned with a brush to prevent dust and crumb accumulation between the surfaces in the next measurement. When a slip of 10% of the length of the test specimens occurred, the sensor automatically stopped the device and measurements were taken.

$$\varphi_b = median\beta_{i=1,..,5} \qquad (3)$$

Schmidt hammer tests were applied to mica schist and green schist cores and discontinuities at 0°, 15°, 30°, 45°, 60°, 75° and 90° orientation angles according to the methods suggested by ISRM (2007).

3. Results

The results in Figures 6, 7, 8, 9, 10 and 11 were obtained in this study to investigate the effect of anisotropy on the basic and residual friction angles in green schist and mica schist rocks. The effect of anisotropy for green schist was observed at a maximum of 60° in experiments conducted under dried and saturated conditions (Figure 6). Dried and saturated media values showed close results.

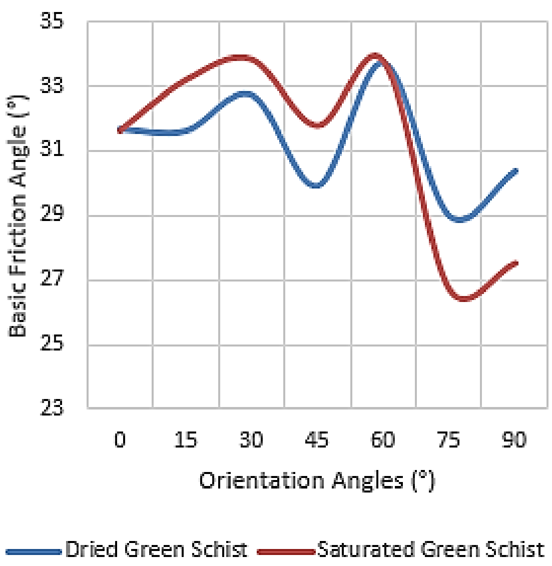

Figure 6. Basic friction angle values for green schist.

According to the results given in Figure 7 for mica schist, the effect of anisotropy was not observed in this rock type. However, the saturated media caused a decrease in the results of mica schist. It is thought that the high number of fracture and crack structures in the mica schist caused these results. The location of the mica schist within the Kastamonu Ekinveren fault zone is effective in the formation of its porous-fractured structure (Tüysüz 1999, Okay *et al.* 2006, Yıldız *et al.* 2014).

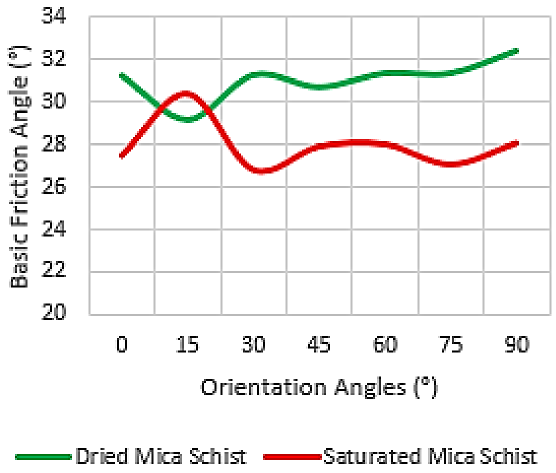

Figure 7. Basic friction angle values for mica schist.

Schmidt hammer rebound values (R and r) are needed for the transition to residual friction angle values of green schist and mica schist rocks (Equation 2). Accordingly, the Schmidt rebound values (R) on the core, the values 33-46 and 19-31 were obtained for green schist and mica schist respectively (Figure 8).

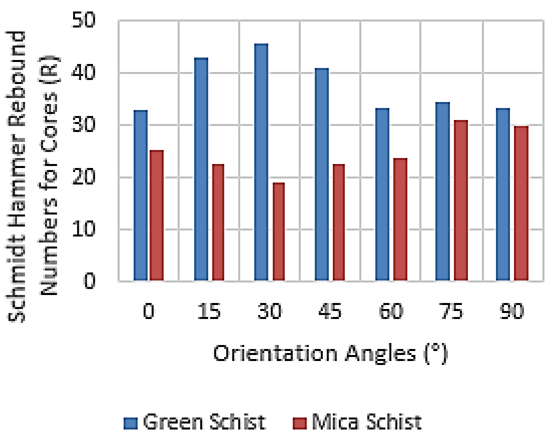

Figure 8. Schmidt rebound values (R) obtained on the core for green schist and mica schist.

According to the Schmidt rebound values (r) performed on the discontinuity (joint), the values 16-23 and 14-18 were obtained for green schist and mica schist, respectively (Figure 9). Because green schist has less cracked and porous structure than mica schist, higher values were occured.

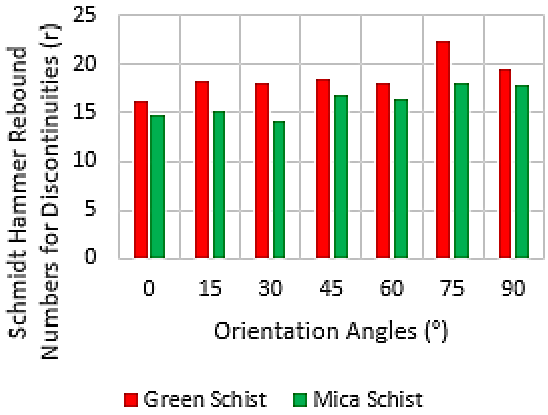

Figure 9. Schmidt rebound values (r) obtained on discontinuity for green schist and mica schist.

Considering the results of the residual friction angles, it was concluded that anisotropy at 60° is an effective parameter for green schist in parallel with the basic friciton angle values, while saturated media is more effective than anisotropy for mica schist (Figures 10 and 11).

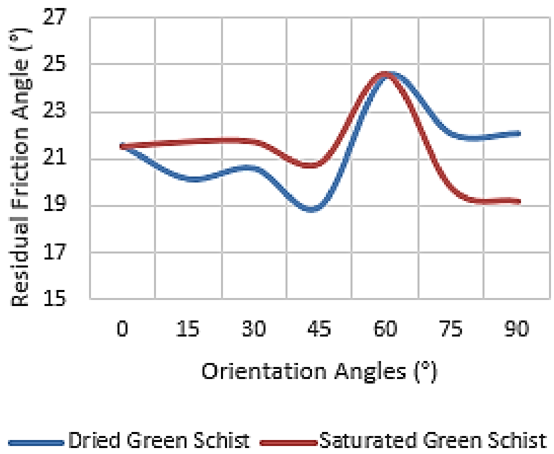

Figure 10. Residual friction angle values for green schist.

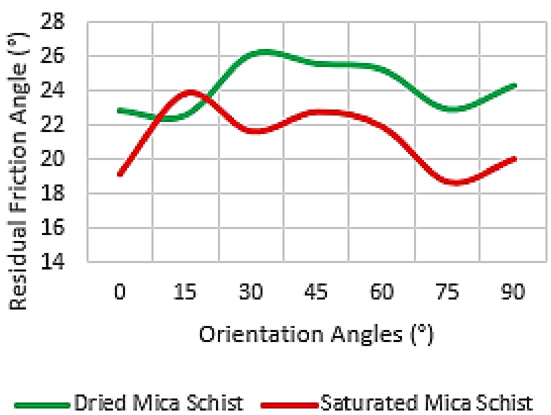

Figure 11. Residual friction angle values for mica schist.

4. Conclusion

In this study, the effect of anisotropy on basic and residual angles was investigated for green and mica schist rocks with a specially designed tilt device. Tilt tests were applied to green schist and mica schist rocks at 0°, 15°, 30°, 45°, 60°, 75° and 90°. Obtained results are summarized below.

- Anisotropy is considered to be an effective parameter in green schist rock for the basic and residual friction angles. Maximum results were obtained in dried and saturated conditions at 60°. In dried and saturated medias, close results were seen compared to the mica schist in basic and residual friction angles. Water had a lesser effect on the results because green schist had less porous and cracked structure.
- The results obtained (Figures 7 and 11) show that anisotropy does not show much effect in mica schist rock. It was determined that the water was effective in the results due to the porous and cracked structure of the mica schist and reduced the basic and residual friction angle values in the saturated conditions.
- It was observed that the basic friction angle values for green schist and mica schist rocks ranged from 26.7° to 33.8°, and the values from 18.7° to 26.1° for the residual friction angle.
- The rock mechanical effect of both anisotropy and water must be determined in fractured and cracked rocks where underground and surface engineering structures are planned.
- Foliation, schistosity etc., it is understood that anisotropy, which is a rock feature that changes on the basis of orientation according to bedding, is a parameter that must be investigated, especially in metamorphic rocks.

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5. References

Ajalloeian, R. and Lashkaripour, G.R., 2000. Strength anisotropies in mudrocks. *Bulletin of Engineering Geology and the Environment*, **59(3)**, 195–199.

Alejano, L. R., González, J. and Muralha, J., 2012. Comparison of different techniques of tilt testing and basic friction angle variability assessment. *Rock Mechanics and Rock Engineering*, **45(6)**, 1023–1035.

Alejano, L. R., Muralha, J., Ulusay, R., Li, C. C., Pérez-Rey, I., Karakul, H., Chryssanthakis, P. and Aydan, Ö., 2018. ISRM Suggested Method for Determining the Basic Friction Angle of Planar Rock Surfaces by Means of Tilt Tests. *Rock Mechanics and Rock Engineering*, **51(12)**, 3853–3859.

Barton, N. R., 2016. Non-linear shear strength for rock, rock joints, rockfill and interfaces. *Innovative Infrastructure Solutions*, **1(1**), 1–19.

Barton, N. R., 2013. Shear strength criteria for rock, rock joints, rockfill and rock masses: Problems and some solutions. *Journal of Rock Mechanics and Geotechnical Engineering*, **5(4)**, 249–261.

Barton, N. R. and Bandis, S. C., 2017. Characterization and modeling of the shear strength, stiffness and hydraulic behavior of rock joints for engineering purposes. *Rock Mechanics and Engineering*. 1–38.

Beyhan, S. and Özdemir, M., 2021. Evaluation of the basic friction angle in dry and conditioned fluids by tilt tests. *IOP Conference Series: Earth and Environmental Science*.

Cho, J.W., Kim, H., Jeon, S. and Min, K.B., 2012. Deformation and strength anisotropy of Asan gneiss, Boryeong shale, and Yeoncheon schist. *International Journal of Rock Mechanics and Mining Sciences*, **50(1)**, 158–169.

González, J., González-Pastoriza, N., Castro, U., Alejano, L. R. and Muralha, J., 2014. Considerations on the laboratory estimate of the basic friction angle of rock joints. *EUROCK 2014, ISRM European Regional Symposium*. Vigo, 199–204.

Huang, L., Liu, X., Yan, S., Xiong, J., He, H. and Xiao, P., 2020. Experimental study on the acoustic propagation and anisotropy of coal rocks. *Petroleum*, **8(1)**, 31-38.

Ismael, M., Lifu, C. and Konietzky, H., 2017. Behavior of Anisotropic Rocks. *E-Book*, July.

ISRM 2007. The complete ISRM suggested methods for rock characterization, testing and monitoring*:* R. Ulusay and J. A. Hudson (eds). Kozan Ofset, Ankara, 1974-2006.

Jang, H. S., Zhang, Q. Z., Kang, S. S. and Jang, B. A., 2018. Determination of the Basic Friction Angle of Rock Surfaces by Tilt Tests. *Rock Mechanics and Rock Engineering*, **51(4)**, 989–1004.

Kim, D. H., Gratchev, I., Hein, M. and Balasubramaniam, A., 2016. The Application of Normal Stress Reduction Function in Tilt Tests for Different Block Shapes. *Rock Mechanics and Rock Engineering*, **49(8)**, 3041–3054.

Nasseri, M. H. ., Rao, K. . and Ramamurthy, T., 2003. Anisotropic strength and deformational behavior of Himalayan schists. *International Journal of Rock Mechanics and Mining Sciences*, **40(1)**, 3–23.

Okay, A. I., Tüysüz, O., Satir, M., Özkan-Altiner, S., Altıner, D., Sherlock, S. and Eren, R. H., 2006. Cretaceous and Triassic subduction-accretion, high-pressure-low- temperature metamorphism, and continental growth in the Central Pontides, Turkey. *Bulletin of the Geological Society of America*, **118(9-10)**, 1247–1269.

Özdemir, M., 2021. Slope stability analyzes in metamorphic rock masses with anisotropic behaviour, PhD Thesis, Kütahya Dumlupinar University, Institute of Graduate Programs, Kütahya, 154.

Ramamurthy, T., Rao, G. V. and Singh, J., 1993. Engineering behaviour of phyllites. *Engineering Geology*, **33(3)**, 209–225.

Ruiz, J. and Li, C., 2014. Measurement of the basic friction Angle of rock by three different tilt test methods. *ISRM Regional Symposium-EUROCK 2014*. ISRM, Vigo, Spain, 260–266.

Salager, S., François, B., Nuth, M. and Laloui, L., 2013. Constitutive analysis of the mechanical anisotropy of Opalinus Clay. *Acta Geotechnica*, **8(2)**, 137–154.

Saroglou, H. and Tsiambaos, G., 2008. A modified Hoek–Brown failure criterion for anisotropic intact rock. *International Journal of Rock Mechanics and Mining Sciences*, **45(2)**, 223–234.

Tang, Z. C., Zhang, Q. Z. and Peng, J., 2020. Effect of Thermal Treatment on the Basic Friction Angle of Rock Joint. *Rock Mechanics and Rock Engineering*, **53(4)**, 1973–1990.

Tüysüz, O., 1999. Geology of the Cretaceous sedimentary basins of the Western Pontides. *Geological Journal*, **34(1-2)**, 75–93.

Ulusay, R. and Karakul, H., 2016. Assessment of basic friction angles of various rock types from Turkey under dry, wet and submerged conditions and some considerations on tilt testing. *Bulletin of Engineering Geology and the Environment*, **75(4)**, 1683–1699.

Wang, P., Ren, F., Miao, S., Cai, M. and Yang, T., 2017. Evaluation of the anisotropy and directionality of a jointed rock mass under numerical direct shear tests. *Engineering Geology*, **225**, 29–41.

Wang, P., Yang, T. and Zhou, J., 2018. Slope failure analysis considering anisotropic characteristics of foliated rock masses. *Arabian Journal of Geosciences*, **11(9)**, 222-237.

Xu, G., He, C. and Chen, Z., 2019. Mechanical behavior of transversely isotropic rocks with non-continuous planar fabrics under compression tests. *Computers and Geotechnics*, **115(7)**, 1–29.

Yıldız, H., Günay, K., Şahin, Ş., Niğdeli, S. F. and İçli, M. Y., 2014. Hanönü (Kastamonu) Copper Site (Ar: 201300022) mining geology report based on discovering request, Ankara.

Zhang, N., Li, C. C., Lu, A., Chen, X., Liu, D. and Zhu, E., 2018. Experimental studies on the basic friction angle of planar rock surfaces by tilt test. *Journal of Testing and Evaluation*, **47(1)**, 256–283.

Zhang, X.P., Wong, L. N. Y., Wang, S.J. and Han, G.Y., 2011. Engineering properties of quartz mica schist. *Engineering Geology*, **121(3–4)**, 135–149.