Evaluation of the basic friction angle in dry and conditioned fluids by tilt tests

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Abstract. The basic friction angle is a basic parameter used in the shear strength estimation of discontinuities. The accurate determination of the shear strength of the discontinuities is of great importance for engineering structures built on or inside the rock. In this study, the variation of the basic friction angle tests under dry and different fluid conditions were carried out. For this purpose, a tilt device was designed. 7 different types of travertine samples with dimensions of 10x10x2 cm were used in the experiments. Tilt tests; to determine the change of the basic friction angle under different liquid conditions, dry, pH2, pH7 and pH12 were carried out under different test fluid conditions. Basic friction angles were measured 5 times in each group experiment. Initial basic friction angles were high regardless of sample type and experimental conditions. But; as the measurements continued, significant changes were observed about slip angles. The lowest basic friction angle was obtained in samples conditioned with pH2 while the highest angle was obtained in samples with pH7 conditioned. Thus, the effect of different water contents on sliding surfaces was determined experimentally. It is thought that this study can contribute to the existing studies on the basic friction angle with the tilt test.

1. Introduction
The engineering properties of rock masses are greatly influenced by the sliding behaviour of joints. The main factors affecting the shear strength of an unfilled joint are rock, roughness, size of the joint, the degree of weathering, the strength of the joint surfaces, moisture and water pressure [1]. Discontinuities in rock masses are generally rough. Rough joints without natural filling’s peak strength behaviour is expressed as follows [2].

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

(1)

$\tau$ shear strength of the joint, $\sigma_n$ normal stress applied to the joint, $\varphi_r$ residual friction angle, JRC the joint roughness coefficient, JCS the compressive strength of the joint surface. The residual friction angle, $\varphi_r$ is estimated according to Barton and Choubey [3] as follows:

$$\varphi_r = (\varphi_b - 20^\circ) + 20 \frac{r}{R}$$

(2)

$\varphi_b$ is the basic friction angle, $r$ is the Schmidt hammer rebound number recorded for a weathered and wet discontinuity, such as those normally found in the field, and $R$ is the Schmidt hammer rebound number recorded for the unweathering surfaces of the same rock.

The basic friction angle $\varphi_b$ of planar discontinuities is used to estimate the shear strength of discontinuities in rock engineering projects. $\varphi_b$ is an important parameter to solve stability problems in
underground excavations, surface slope studies and designs [4]. The $\varphi_b$ value takes values as 25°–30° for sedimentary rocks and 30°–35° for igneous and metamorphic rocks [4]. The value of $\varphi_b$ can be measured through tilt tests and direct shear tests on fresh planar surfaces. The values can be obtained by different tilt test methods [5–7].

2. Test Methods

2.1. Tilt Table

The tilt test is the easiest and simplest method of estimating the fundamental friction angle from the sliding angle of the sample as shown in figure 1 [4,8–10]. In recent years, automatic test systems have been used in slope tests. [4,11,12]. The automatically controlled tilt tester designed by the authors of this study, was used in experimental studies (figure 1a). The device has an electric motor system and a 30 × 40 cm inclination plate. Right and left-sided fixing apparatus is mounted on inclination plate to ensure that the specimen slides only in the direction of maximum inclination of the plate. The increasing slope rate can be adjusted between 5.2°/min and 21°/min. Also, using the detecting sensor (figure 1b), the exact slip time is recorded and the tester can be stopped. The device has a digital inclinometer that can measure the angle of inclination with an accuracy of ± 0.1°. When the upper block placed on the fixed lower block slides >16 mm, the system is automatically stopped by the sensor (figure 1d).

![Figure 1](image1.png)

**Figure 1.** Tilt device overview (a), test sensor (b), speed control panel (c), sample slide distance (d).

2.2. Test Procedure

In the studies conducted to estimate the basic friction angles of joints from the tilt test, the sample shapes shown in figure 2 are generally used. In these studies, two rectangular plates, rock core samples cut along a diametral plane, surface contact test methods with two or three cores are suggested [13].
In this study, two rectangular plate samples as suggested in figure 2a were used. Rectangular samples are characterized by three dimensions as shown in figure 2e: length (l), width (w), and height (h). Such samples should have a length/height ratio (l/h) greater than 4 but value greater than 6 are also recommended. In addition, the width/height (w/h) ratio 4 is recommended. Contact surfaces (l×w) should be larger than 50 cm

In this study, a total of 7 travertine rock types were used from Turkey's natural sedimentary stone quarries and processing plants in different regions (figure 3). The sample surfaces are zoomed in different coloured rectangular shapes. The experimental study was conducted in dry and soaked conditions. Samples were soaked with a solution with pH2, pH7 and pH12 conditions until the soaked sample weights remained constant (approximately 48 hours). The sample of each rock type was tested dry and soaked with pure water at pH2, pH7, pH12 for a total of 20 tests.

Figure 2. Different tilt test methods. Rectangular prism sample (a), lengthwise cut core sample (b), three core set-up(c), two core set-up (d), dimensional representation of rectangular plate (e).

Figure 3. General view of 7 different rock types used in the study.
3. Experiment Results

The basic friction angle ($\phi_b$) for rock surfaces was calculated as the median value of the inclination angles which samples were performed for five times [13]. The contact surfaces of the samples were cleaned after each test. Thus, each experiment was repeated on a clean surface.

$$\phi_b = median\beta_{i=1...5}$$

In this study, the basic friction angle of each sample was measured for 20 times and the variation of the angles with the test conditions was investigated. As a result of the test, the values given in table 1 and figure 4 were obtained.

| Rock Type | Dry | Median $\phi_b$ (°) | Number of tests | pH2 | Median $\phi_b$ (°) | Number of tests | pH7 | Median $\phi_b$ (°) | Number of tests | pH12 | Median $\phi_b$ (°) | Number of tests |
|-----------|-----|---------------------|-----------------|-----|---------------------|-----------------|-----|---------------------|-----------------|-----|---------------------|-----------------|
| KC        | 5   | 29,4                | 5               | 22,1| 5                   | 33,0            | 5   | 31,2                |                 |     |                     |                 |
| AN        | 5   | 33,8                | 5               | 27,1| 5                   | 30,3            | 5   | 28,6                |                 |     |                     |                 |
| US        | 5   | 34,4                | 5               | 18,4| 5                   | 30,5            | 5   | 29,8                |                 |     |                     |                 |
| DC        | 5   | 24,7                | 5               | 24,3| 5                   | 31,5            | 5   | 26,8                |                 |     |                     |                 |
| AB        | 5   | 36,2                | 5               | 37,2| 5                   | 32,9            | 5   | 31,3                |                 |     |                     |                 |
| KK        | 5   | 29,1                | 5               | 19,7| 5                   | 33,0            | 5   | 33,3                |                 |     |                     |                 |
| AE        | 5   | 33,8                | 5               | 30,1| 5                   | 33,7            | 5   | 32,0                |                 |     |                     |                 |
| Total     |     |                     |                 | 31,6|                     |                 | 25,6|                     |                 |     | 32,1                |                 |

Figure 4. Different Results of the tilt test of the samples.

Density, porosity, uniaxial compressive strength, P wave velocity and water absorption values for each sample were determined using the test methods recommended by the International Rock Mechanics Association (ISRM) [14] (table 2).
4. Conclusion
The basic friction angle is an important input parameter in estimating the shear strength of joints. The basic friction angle is also obtained from tilt tests. In this study, the basic friction angle of travertine samples was determined for dry and soaked samples. For this purpose, a tilt test device has been designed. Thanks to this device, the test can be subjected to the tilt test in the desired speed range (5.2°/min to 21°/min). Besides, the device can stop automatically with the signal from the sensor after the sample slips 16 mm. With the speed adjustment, the vibrations that may occur in the device are kept at a minimum. Thus, automatic termination of the experiment blocks sample fall and being damaged.

The data obtained as a result of the experimental study; it was determined that the samples conditioned at pH2 had the lowest \( \phi_b \) value on average. Similar results were obtained in experiments conducted under other conditions. The fact that the conditioning liquid was at pH2 caused the slope angles of the samples to be low. Thus, it is thought that the shear strength of carbonate rocks may be lower in soaked field conditions with low pH value.

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**Table 2. Physical and mechanical properties of test specimens [15].**

| Test name | Rock Type | KC | AN | US | DC | AB | KK | AE |
|-----------|-----------|----|----|----|----|----|----|----|
| Unit weight (kN/m³) | | 23.4 | 24.6 | 23.7 | 27.3 | 24.4 | 25.2 | 24.3 |
| Apparent porosity (%) | | 4.20 | 2.31 | 7.85 | 5.44 | 2.78 | 2.19 | 3.95 |
| Water absorption (%) | | 1.39 | 1.62 | 3.31 | 1.61 | 0.77 | 0.96 | 0.82 |
| P wave speed (m/sn) | | 4829 | 5418 | 5319 | 5229 | 5418 | 5439 | 5075 |
| UCS (MPa) | | 52.08 | 59.95 | 51.86 | 34.45 | 42.09 | 42.45 | 57.14 |
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