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Determination of the basic friction angle ϕb of joints using the field tilt test: results of various "fast" tests on outcrops

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Abstract. The basic friction angle of rock joints is usually obtained from tilt tests, being the most common the laboratory tilt tests. This test has been standardized according to the ISRM. However, most of the times when calculating the shear strength of discontinuities, reference tables are used to obtain the basic friction value for the lithology under study. These tables omit some lithologies complicating the search of adequate references. An alternative, straightforward and economical way to obtain ϕ_b is through the field tilt test, which is carried out by sliding two blocks aside a joint. It is a well-known test, but there are few references to its implementation. In this test, unlike the laboratory tilt test, the samples are not "polished" and it is necessary to evaluate the roughness of the joint and the normal component to the weight of the upper blocks. The idea is to calculate the term of ϕ_b from the Barton-Bandis' equation and include the tilt angle α. Various tilt-test measurements were carried out with field blocks on both sides of the same joint, considering different lithologies (granite, limestone, andesite, dacite, coal and slate) and block sizes, evaluating the ideal ranges of applicability of the test.

1. Introduction

The basic friction angle of joints is a fundamental parameter in the kinematic analysis of different types of block failures in slopes and underground excavations. Its adequate evaluation in a daylight and friction circle stereographic diagram can make the difference that something becomes stable or unstable.

One of the most widely used criteria for determining the shear strength of discontinuities is the nonlinear Barton-Bandis [1]. In a previous version of this criterion [2] a term referred to the residual friction (ϕ_r), is introduced.

Basic friction angle is a key parameter in the determination of residual and peak friction angles of a discontinuity according to Barton–Bandis [1] criteria. The tilt test is widely used for the determination of basic friction of discontinuities. This test is usually performed at laboratory using two slab-like specimens, or three drilling cores, although the test can also be performed in the field. However, in practise, it is quite common to use tables to estimate the value of the basic friction angle for each type of rock [3, 4]. The problem is that some rock types are not included in the above-mentioned tables since their basic friction angles have not yet been determined or published. It is sometimes very complicated and arduous searching for references, especially those referring to rocks like granodiorites, rhyolites, dacites, andesites or carbon.

A quick, simple and inexpensive way to effectively obtain this value of φ_b is through the field tilt test, which is carried out by sliding two blocks aside a joint. It is a well-known test, but there are few references to its implementation [5,6,7,8]. In this test, unlike the laboratory tilt test, the specimen contact surfaces are not "polished" and it is necessary to evaluate the roughness of the joint and the normal component to the weight of the upper blocks. The approach of this research is to calculate the term of φ_b from the Barton-Bandis formulation (equation 1) [1] and include the tilt angle α [6]. Within our research, various tilt test measurements were carried out with field blocks on both sides of the same joint, considering different lithologies (granite, limestone, andesite, dacite, coal and slate) and block sizes, evaluating the ideal ranges of applicability of the test.

The shear strength of a rough discontinuity can be defined according to Barton–Bandis [1, 9] empirical criterion:

$$\tau = \sigma_n \tan\left[\phi_r + JRC \log_{10}\left(\frac{JCS}{\sigma_n}\right)\right] \tag{1}$$

being the residual friction given by equation 2:

$$\phi_r = (\phi_b - 20) + 20\left(\frac{r}{R}\right) \tag{2}$$

where:

- σ_n is the effective normal stress acting on the fracture surface.
- JRC is the joint roughness coefficient that is obtained from standardized profiles.
- JCS is the compressive strength of the rock at the fracture surface obtained using Schmidt's hammer.
- "r" is the Schmidt hammer rebound number on wet and weathered fracture surfaces.
- "R" is the Schmidt rebound number on dry unweathered sawn surfaces.

According to Barton [6] the peak friction of the discontinuity can be calculated as:

$$\phi_p = \phi_r + JRC \log_{10}\left(\frac{JCS}{\sigma_n}\right) \tag{3}$$

And then, Equation 4 can be used for the determination of roughness [6]:

$$JRC = \frac{\alpha - \varphi_r}{\log_{10}\dfrac{JCS}{\sigma_{n0}}} \tag{4}$$

Figure 1 shows the procedure used at field to perform the tilt test.

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Figure 1. Development of tilt test on field [10].

In this work, the basic friction angle (φb) and the the tilt angle (α) are evaluated using the tilt test in the field for some lithologies that are not present in standard reference tables of values such as granodiorites, rhyolites, dacites, andesites and carbon.

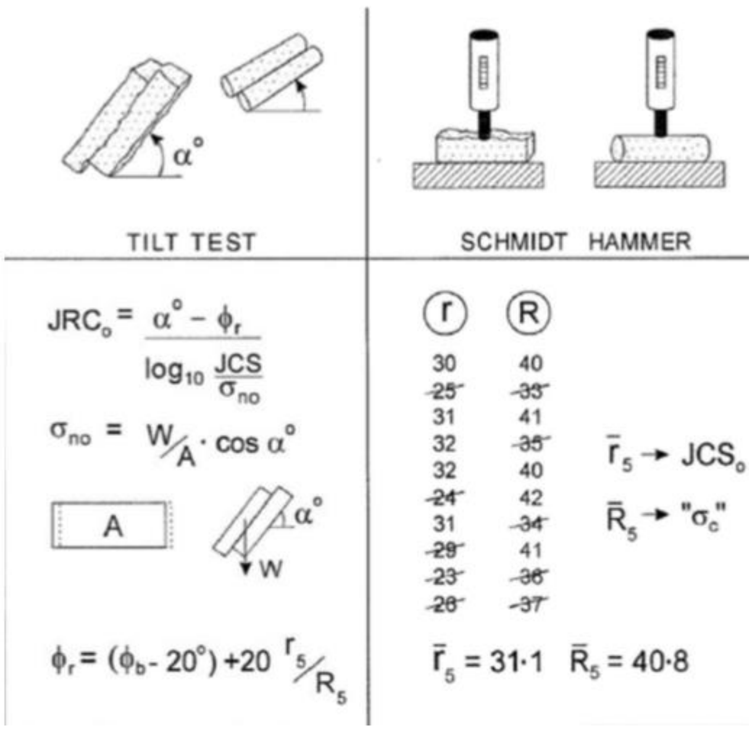

Figure 2. Field tilt test strategy according to Barton [6].

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2. Methodology

Firstly, the basic friction angle has to be determined from the so-called 'tilt angle'. The rest of parameters have to be determined in the field. The basic and residual friction angle can be found from Equations 5 and 6.

$$\phi_b = \phi_r + 20 - 20\frac{r}{R} \quad (5)$$

$$\phi_r = \alpha - JRC_0\left(\log_{10}\frac{JCS_0}{\sigma_{n0}}\right) \quad (6)$$

The rest of parameters are determined in the way shown in table 1.

Table 1. Methodology determination of the shear strength parameters.

Parameter	Determination
Rebound "r"	According to Barton (2014), in a 20 repetition test the highest 5 values from the 10 lowest ones.
Rebound "R"	From a 20 Schmidt's hammer tests, the highest 5 values are taken
JRC_0	Determined with Barton's comb on the joint and sliding direction
JCS_0	According to Barton (2014), this parameter is determined from a R vs. UCS chart
σ_{n0}	Normal stress on the joint corresponds to the normal component of the weight divided by the apparent contact area.

We follow the methodology suggested by Barton [6], as described in Jordá-Bordehore and Espada [7]. We show this procedure in figure 3. Procedure is as follows:

- An adequate joint for testing has to be located. The upper and lower block forming the discontinuity has to be extracted from the rock mass. This ensures a perfect coupling of rough joints. If any two blocks are selected, the contact between them will be scarce and the test results may be incorrect. In very smooth joints this aspect is not so relevant.
- In the rock mass where the block was extracted, 20 N-type sclerometer rebound tests are carried out. All of them in the same direction (vertical or horizontal). Schmidt's hammer tests are not carried out on the sample to avoid breaking it.
- Joint roughness is recovered with the Barton comb in the direction along the sliding direction.
- The upper block is weighed, and the contact area is estimated.
- One block is placed on top of the other, with the joint resting on a horizontal plane. The angle measurement can be done with a compass on the joint or using a tilt table.
- The two-block set is progressively turning but preventing the interaction with the upper block the one that will have to be in contact according to its own weight without external forces.
- Once the upper block starts to slide, the test is stopped. The angle between the joint ad the horizontal plane is the angle of inclination α. If the upper block overturns, the test is not valid.
- We apply equations 5 and 6 to obtain the basic angle φb for each of the measurements.

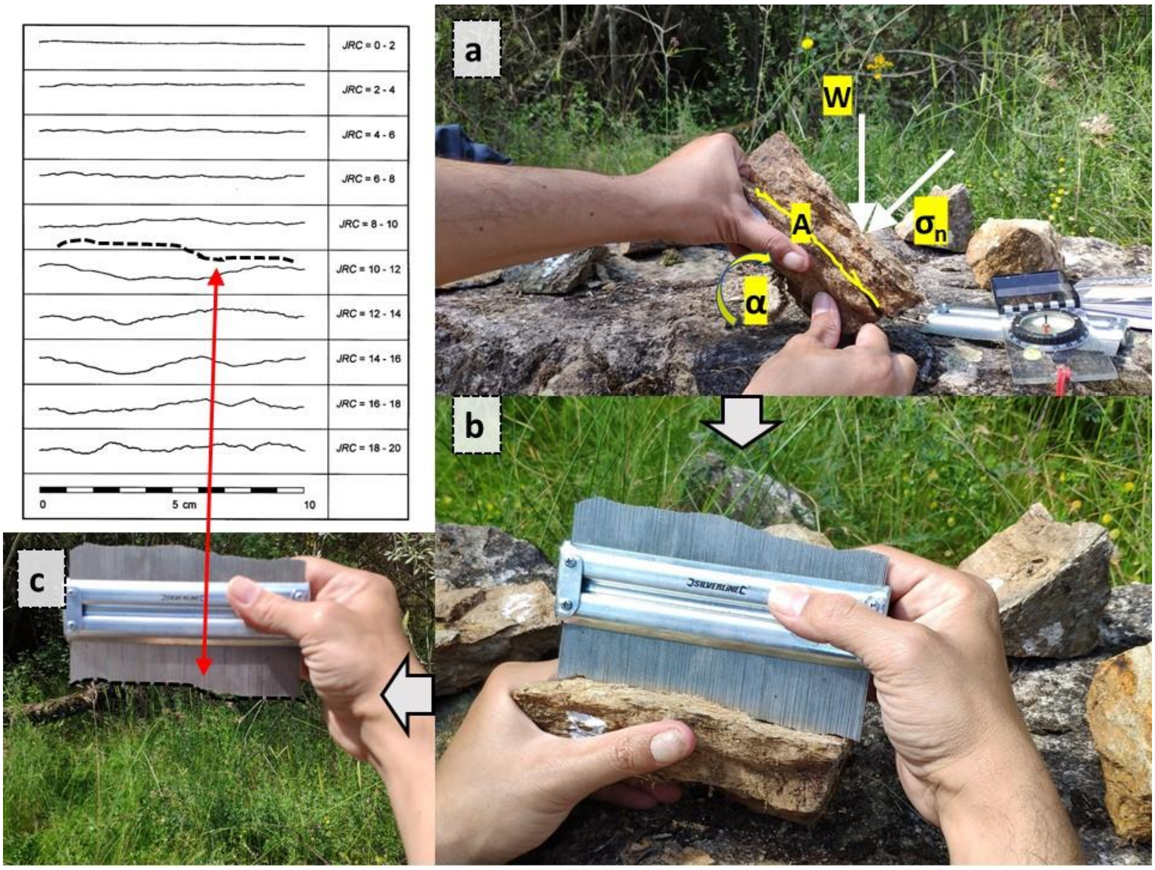

Figure 3. Field work carried out: a) field measurement of tilt angle α with a compass, weigh of the upper block W and contact area A b) roughness measurement JRC and d) comparison with Barton and Choubey [2] abacus.

3. Results and discussion

We carried out 23 field tests using simples from three different rocks: volcanic – igneous (rhyodacite), sedimentary (limestone and sandstone) and metamorphic (schist). We found out that some results have no geotechnical sense: negative φr values. These results occur in some simples with high JRC values (above 8) and big ratios r/R. This situation was recognized both in schists and limestone, but not in rhyodacites where JRC values were low and consistent (around 3-4).

The standard deviation (see table 3) of the basic friction angle of schists and limestones (without considering those anomalous data) is very high. Thus, in this case the ϕ_b value may not be typical of those materials. The comparison with Coulson values [11] are very different for the limestone (ϕ_b 35-40) or sandstone (ϕ_b 31-34) but similar for the schists – gneiss schistose (ϕ_b 23-29). Coulson values [11] for instance where defined for flat surfaces and the analysed methodology is for rough surfaces where the basic friction angle is obtained after a series of factor and calculations that may introduce some scattering. We are going to investigate other lithologies and variations of the input parameters (*JCS, r, R, JRC, A, W*) in order to establish if some of them influence the results more that others and the thresholds for “non-sense” negative values of ϕ_r and ϕ_b.

Table 2. Field test results and parameters.

Test	Location (year test)	Lithology (wet-dry)	Schmidt's hammer rebounds		JCS_0	Upp. block weight, W	Theor. contact surface	α	JRC_0	ϕ_r	ϕ_b
			r (no.)	R (no.)	MPa	g	cm^{-2}	º	—	º	º
1	Pedrezuela	Schist (dry)	30	50	23	837.5	150	48	5	24.05	32.05
2	Spain		30	50	23	837.5	150	60	11	5.93	13.93
3	(2020)		30	50	23	984.6	200	26	9	-16.44	Non sense
4	Potosí	Rhyodacite	36	38	18	7280	400	40	4	23.56	24.61
5	Bolivia	(dry)	36	38	18	7280	400	42	4	25.50	26.56
6	(2015)		36	38	18	7280	400	44	4	27.45	28.50
7			36	38	18	7280	400	35	4	18.67	19.73
8			36	38	18	1300	100	36	3	23.30	24.35
9			36	38	18	1300	100	37	3	24.28	25.34
10			36	38	18	1300	100	34	3	21.33	22.38
11			36	38	18	1300	100	32	3	19.36	20.41
12			36	38	18	1300	100	40	3	27.23	28.28
13			36	38	18	1300	100	50	3	37.00	38.05
14			36	38	18	1300	100	52	3	38.94	40.00
15			36	38	18	1300	100	44	3	31.15	32.20
16			36	38	18	1300	100	56	3	42.82	43.87
17	Patones quarry	Limestone (wet)	24	33	19	2276	224	35	12	-17.30	Non sense
18	Spain (2021)	Limestone (dry)	24	33	19	581	44	55	17	-19.79	Non sense
19			24	33	19	347	40.5	56	7	23.81	29.27
20			24	33	19	1291	99	28	4	11.13	16.58
21			24	33	19	438	30	35	9	-2.81	Non sense
22			24	33	19	305	31.5	55	7	23.26	28.72
23			24	33	19	448	60	60	9	17.64	23.09
24			24	33	19	1180	100	40	13	40.00	45.45
25	Guayaquil	Sandstone	51	58	62	1230	134.9	58	4	37.57	39.98
26	Ecuador	(damp)	51	58	62	4020	180.9	60	4	41.01	43.43
27	(2021)		51	58	62	1476	229.7	73	6	39.89	42.30
28			43	51	58	284	45.3	66	7	28.50	31.64
29			43	51	58	334	42.6	76	8	32.12	35.25
30			43	51	58	412	33.3	75	8	32.94	36.07
31			43	54	60	972	128.6	63	6	31.54	35.62
32			43	54	60	7168	169.3	60	6	33.29	37.36
33			43	54	60	2462	291.1	61	6	30.01	34.08

Table 3. Basic friction angles obtained from field tilt test.

Lithology	Mean value (º)	Std. Dev (º)	Median (º)
Schist (dry)	23	12.8	23
Rhyodacite (dry)	28.8	7.6	26.6
Limestone (dry)	24.3	14.	25.9
Sandstone (damp)	37.3	3.9	36.1

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4. Concluding remarks

In the communication, we present the results of various geotechnical campaigns carried out in Spain, Bolivia and Ecuador with the field tilt test. This is a very simple and very reliable test and yet we do not think it is used enough. It is a procedure that can be implemented in any investigation and work in an economic and fast way and then be contrasted with other tests in more advanced stages of a project. We believe that the extensive data show in the present work comes to fill a gap in the literature in this regard.

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