A portable tilting table for on-site tests of the friction angles of discontinuities in rock masses

Une table inclinable et portative pour les epreuves sur le terrain des angles de frottement des stratifications dans les massifs rocheuses

Hu, Xian-Qin
Department of Geology, University of Alberta
Edmonton, Alberta, Canada
T6G 2E3

Cruden, D.M.
Department of Civil Engineering
University of Alberta
Edmonton, Alberta, Canada
T6G 2G7

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Abstract

A portable tilting table can determine the friction angles of smooth surfaces of discontinuities for the assessment of rock slope stability. The lower bound of tests on sandstones is close to the upper bound of results from surfaces lapped with #80 grit, which give basic friction angles. Siltstones and shales can also be tested at the site when specimens may not survive transportation to the laboratory.

Resumé

On peut determiner les angles de frottements des stratifications lisses en utilisant une table portative qui pivote. Les résultats aident l'evaluation de stabilite des massifs rocheuses qui contienent ces stratifications. La limite inférieure des epreuves des gres approche la limite supérieure de l'angle de frottement fondamental. Les échantillons fragiles des schistes ne survivent pas leur transportation au laboratoire; on peut évaluer ces roches sur le terrain.

Introduction

Determinations of friction angles of discontinuities in rock masses are essential for the evaluation of the stability of slopes in these masses. The use of direct shear boxes requires careful transport of specimens from the field, cutting them to specified shapes, lapping rock surfaces if necessary and spending at least a day to test a sample. Since Hoek and Bray (1974) first suggested that the angle of friction could be obtained by a simple tilt test when a clearly defined failure surface existed, friction angles of artificial rock surfaces and natural discontinuities have been estimated by tilting (Cawsey and Farrar, 1976; Barton and Choubey, 1977; Bruce *et al.*, 1988; Cruden and Hu, 1988).

Testing rocks in a rock mechanics laboratory using a tilting table requires transport of rock samples from the site and, generally, cutting of rock samples in the laboratory. Only a limited number of rock samples can be tested if the site is far from a highway. Rock samples may be broken in transport or when they are sawn.

With tests conducted at the sampling site, test results are available to guide the sampling program. When weak discontinuities are found, as many tests as necessary can be conducted on the discontinuities to establish their friction angles with the required precision. A portable tilting table, designed and built at the University of Alberta, was used to estimate friction angles of bedding surfaces of sandstones in the Highwood Pass, Alberta for a field study of rock toppling (Hu, 1991).

In this paper we first describe the construction of the tilting table and the test procedure and then discuss the testing results in Highwood Pass. We also study the relationship between lithology, rock strength and friction angles of the rocks in Highwood Pass to estimate basic friction angles.

Construction of the tilting table

The table tilts a rock sample until sliding begins on the discontinuity between the two parts of the rock sample. The table is connected to a rigid frame by a hinge so that the table can be rotated about the hinge (Fig. 1). A spring, P, and hydraulic pressure system, H, are used to control rotation of the table. The hydraulic pressure system consists of a reservoir for hydraulic fluid, a cylinder with a piston which is connected to the table and a switch. The three components are connected by the plastic tubes. While the spring pulls and tilts the table, the hydraulic pressure system controls the flow rate of fluid from the fluid reservoir to the cylinder by the switch, which determines the rotation rate of the tilting table.

The tilting table is made from aluminum plate for lightness, it weighs 2.2 kg. The dimensions of the frame are 0.23 m x 0.23 m x 0.18 m and the tilting table can be disassembled for transport. A screw, S, under each foot of the frame can level the frame for testing. The hinged table is equipped with brackets to hold samples up to 0.16 m x 0.16 m. Samples from 0.12 m to 0.3 m thick can be tested. The table rotates from 0° to 46°.

Test procedure

The tilting table is first levelled by adjusting the four foot screws using a fish-eye level. The bottom block of the sample or plate is then placed on the table and held by the brackets. A fish-eye level is placed on the sliding surface and the screws are adjusted to level the sliding surface at the beginning of the test. Then the top block of the sample or slider is placed on the plate. The switch of the hydraulic system is turned open to let the tilting table rotate at 10°/minute. We found that sliding angles did not change noticeably for the rotation rate in the range of 5° to 10°/minute. The angle at which the slider has slid perceptibly, about 2 mm, is the sliding angle and the switch is turned off to stop rotation. The slider generally accelerated after sliding 2 mm. Sliding angles are calculated by the measurements of the vertical displacements of the displaced end of the table and the length of the table. An inclinometer can also be used to estimate the sliding angle. Repeated tests were performed with both the plate and the slider oriented in the same way to evaluate the change of sliding angles and then to estimate average sliding angles.

Testing of bedding surfaces at Highwood Pass

Highwood Pass, Alberta, Canada is west of Calgary and in the Front Ranges of the Canadian Rocky Mountains. The samples were taken from the Triassic Spray River Group (Irish, 1965). The rocks tested are thinly to thickly bedded, brown to yellowish, fine grained sandstones with some shale and siltstone laminae. Thicker sandstone beds are stronger than thinner beds. Strengths of loose materials were rated as S1 to S5 and strengths of rocks were rated R1 to R5 (Piteau, 1973; Herget, 1977, P.88). S1 describes very soft soil and R5 describes very hard rock. Besides the portable tilting table tests, tilting tests were also conducted on both artificial and natural surfaces in the laboratory for comparison.

Portable tilting table tests

The samples for portable tilting table tests were selected to have as smooth testing surfaces as possible since the friction angle can be considerably increased by surface roughness. Dimensions of the samples were measured (Hu, 1991) and strengths of the blocks were estimated and rated using a geological hammer (Herget, 1977). The samples were taken at the ground surface and in dry weather. None of the samples was slickensided.

Thirty-four samples were tested using the portable tilting table. Each sample was tested four times and sliding angles did not vary systematically in repeated tests. The average of the four tests was taken as the friction angle. The samples were divided into nine groups by their lithology and rock strength rating. Hartley's maximum-F test for homogeneity of variance and a one way analysis of variance were conducted on the friction angles of each group (Table 1). Pooled means, standard variations and 95% confidence limits were calculated for the groups which can be considered to be from one population assuming the sliding angles follow a normal distribution.

The significance levels of F-statistics of all the sandstone groups except the R3 group are less than 0.005, which indicates the friction angles of the samples differ within these groups. The crude estimates of rock strength and the different sample surface roughnesses may cause the large variation of friction angles within these sandstone groups. F tests on the groups of shales and siltstones show the samples can be considered to be from the same population. The tests also show the means of friction angles tend to increase with the strengths of materials (Table 1 and Fig. 2).

Tilting tests in the laboratory

Seven sandstone samples selected at random from the Spray River Group were carried back to the laboratory for tilting tests on a tilting table (Bruce *et al.*, 1989). Their strengths are rated as R3 to R4 (Table 2). Five of the samples were tested along natural surfaces. The sliders and plates of the other two samples were sawn to 5 cm x 5 cm and up to 2 cm thick and first the plates and then the sliders were lapped with #80 grit. Table 2 list means and standard variations of the friction angles of all the tests. All the samples were tested four times at a rotation rate of 8°/minute.

The two lapped surfaces have mean sliding angles of 28.3° to 29.2°, estimates of basic friction angles (Cruden and Hu, 1988), which approach the lower bounds of the friction angles of the R3 group (Table 1). Natural sliders over lapped plates give mean sliding angles of 29.8° to 32.8°. For the same sample, the mean sliding angle from two lapped surfaces and that from a natural slider on a lapped plate are significantly different at the level of 95% confidence.

Natural sliders on natural plates from the five samples give sliding angles of 31.7° to 53.4°. The mean sliding angles from the 5 samples of natural sliders on natural plates are significantly higher at the 95% confidence level than the mean sliding angles of lapped sliders on lapped plates and natural sliders on lapped plates. The large range of sliding angles from natural surfaces resulted from their different roughnesses.

Discussion of testing results

The friction angles of R3 sandstone samples from the portable tilting table are higher than those from the two lapped surfaces in the laboratory test, indicating that discontinuity surfaces in the field are rougher than surfaces lapped by #80 grit. However, the lower bound of friction angles is close to the upper bound of sliding angles of surfaces lapped with #80 grit (Fig. 2) so the upper bound of the basic friction angles can be estimated. The variations of the friction angles within sandstone groups other than the R3 group are so large that these groups need to be subdivided further with respect to friction angles.

In the laboratory testing, the rougher natural surfaces over lapped surfaces gives higher sliding angles than two lapped surfaces. Natural surfaces can give considerably high sliding angles if surfaces are very rough. So the sliding angles of the samples depend heavily on the roughness of the sliding surfaces if the lithologies are the same.

Stronger sandstone samples gave higher sliding angles. This may be caused by asperities on the sliding surfaces of weaker sandstones wearing more easily in sliding than those of stronger sandstones. Weaker sandstones are, perhaps, not as well cemented as stronger rocks and may also have higher clay contents.

Bedding surfaces of shales and siltstones have lower sliding angles than those of sandstones. Some fine particles may be produced during sliding and smooth sliding surfaces of shales and siltstones because shales and siltstones are weaker and not as well cemented as sandstones. Sandstones are harder than shales and do not produce fine materials from sliding under low normal loads.

The portable tilting table is suited to smooth discontinuities, such as bedding surfaces. Rough joint surfaces are not suitable for testing using the tilting table because at large angles of tilt the test blocks may topple. Testing programs for rock slopes in sedimentary and metamorphic rocks are however usually directed to finding the smoothest penetrative discontinuities. The table is a practical way to get good estimates of the minimum friction angles of discontinuities.

If the relationship between the friction angle on a natural surface, joint roughness coefficient (JRC), joint wall compressive strength (JCS), normal stress and the basic friction angle (Barton and Choubey, 1977, Equation 6) is to be established, precise determination of the basic friction angle is necessary. Rock blocks can be transported to the laboratory without the need to protect their surfaces. New surfaces can be cut, lapped with #80 grit and tested to obtain basic friction angles. Based on estimates of JRC and JCS, shear strengths and friction angles at different normal stresses may be calculated. The JRC of the surfaces can also be estimated if both the basic friction angle and the friction angles are measured in dry conditions.

Conclusions

The portable tilting table is useful equipment for tilting tests in the field. As many smooth discontinuity surfaces as desired can be selected and tested. The results from the site tests show that the minimum sliding angle on R3 sandstone samples is close to the upper bound of basic friction angles obtained from laboratory tests. Siltstones and shales have lower sliding angles than sandstones. Siltstones and shales can be tested satisfactorily in the field while they may not survive transportation and cutting on the rock saw.

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List of Tables and Figures

Table 1. Statistical analysis of testing results

Gp	No	Li	Sr	F-statistic	Significance Level	Range of means	Pooled mean and SD	95% CL
1	1	slt	S2	N/A	N/A	22.5	N/A	N/A
2	3	sh & slt	S4	1.37	p>0.25	26.8-29.1	28.0± 2.0	26.9-29.1
3	1	sh	S4	N/.A	N/A	28.7	N/A	N/A
4	3	sh & slt	R1	1.99	.1<p<.25	27.2-30.7	28.9 ±2.7	27.4-30.4
5	8	ss	R1	4.88	.001<p<.005	28.2-31.4	N/A	N/A
6	3	ss	R2	11.47	.0001<p<.005	28.3-32.3	N/A	N/A
7	9	ss	R3	2.06	.05<p<.1	30.7-33.2	32.4 ±1.2	32.0-32.8
8	1	ss	R4	N/A	N/A	34.1	N/A	N/A
9	5	ss	R5	12.72	.0001<p<.005	32.5-35.8	N/A	N/A

Gp: Group; No: Number of samples in a group (4 tests done on each sample); Li: Lithology; Sr: rock strength rating; SD: Standard deviation; CL: Confidence limit; N/A: Not applicable.

sh: Shale; slt: Siltstone; ss: Sandstone.

Table 2. Test results of tilting tests in the laboratory

sample	Plate surface	Slider surface	Strength Rating	Mean and standard deviation of sliding angles (in degree)
1	Natural	Natural	R4	52.3±3.1
2	Natural	Natural	R3	53.4±2.5
3	Natural	Natural	R4	37.5±0.6
4	Natural	Natural	R3	35.6±2.5
5	Natural	Natural	R4	31.7±1.5
6	Lapped with #80 grit	Natural	R4	32.8±1.3
6	Lapped with #80 grit	Lapped with #80 grit	R4	29.2±3.2
7	Lapped with #80 grit	Natural	R3	29.8±1.0
7	Lapped with #80 grit	Lapped with #80 grit	R3	28.3±1.0

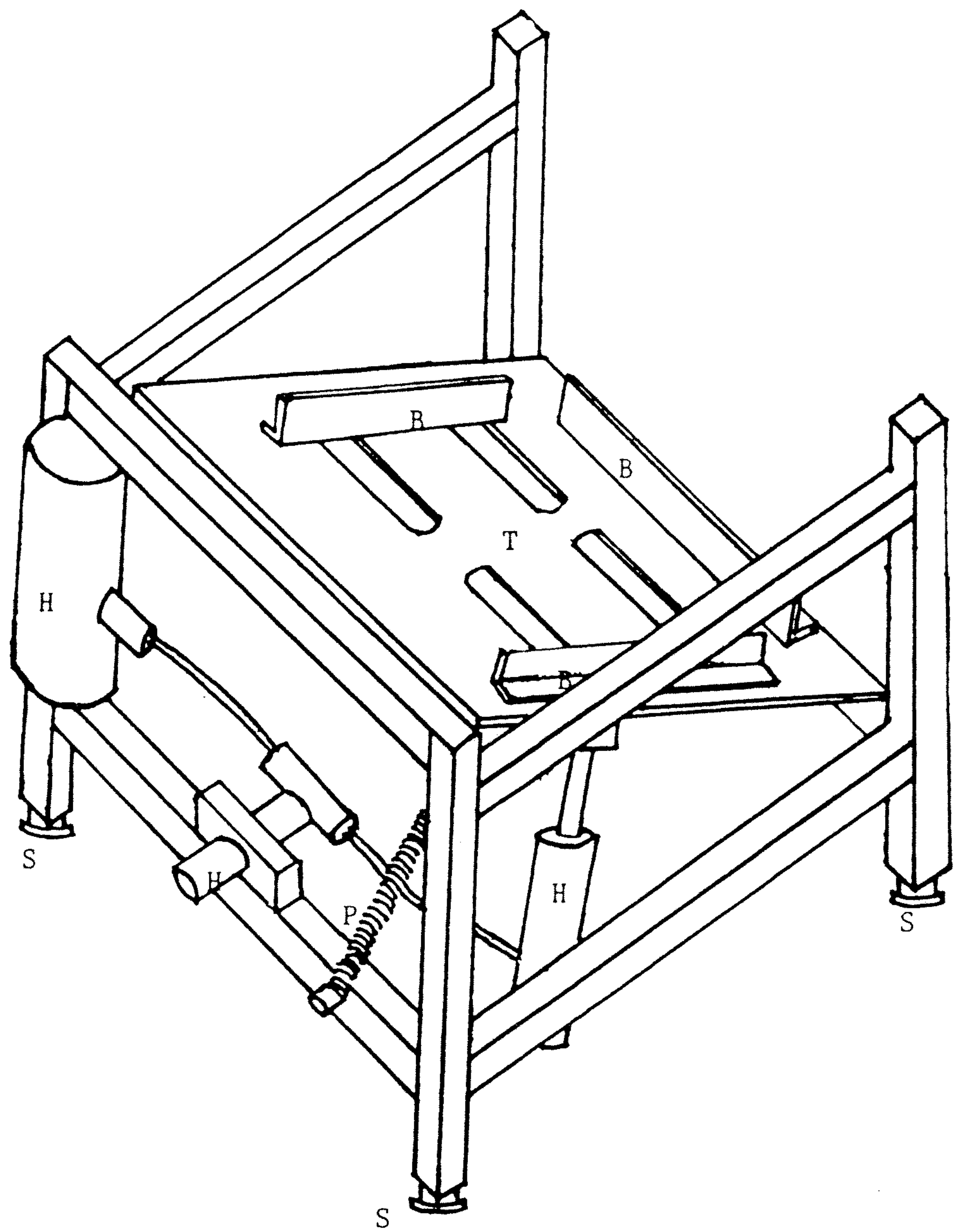

Figure 1. The portable tilting table. In the figure, T, B, H, S and P represent the tilting table, brackets, hydraulic system, adjustable screws and the spring.

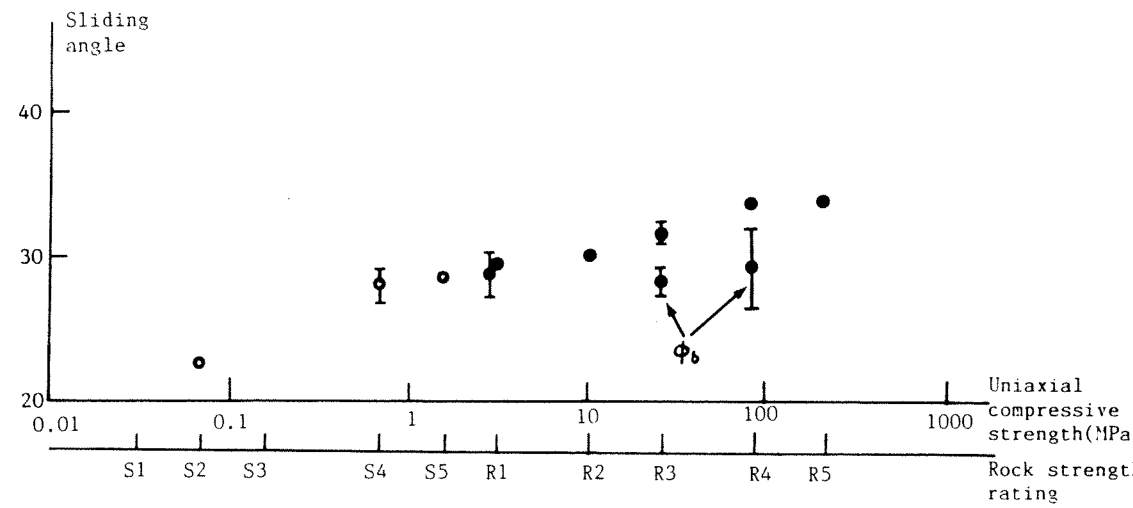

Figure 2. Relationship between strengths of rock blocks and sliding angles. S1 to S5 and R1 to R5 are strength ratings (Herget, 1977). The bars represent 95% confidence interval and the circles represent mean values of sliding angles. The open circles are shales and siltstones and the solid circles are sandstones. ϕ_b is the basic friction angle.