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Sample Type of Tilt Testing and Basic Friction Angle Value for the Crocker Formation's Fine Sandstone of Sabah, Malaysia

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The basic friction angle is an essential input in estimating the shear strength of joints in stability analysis of rock slopes, underground excavations and assessment of factors of safety in rock engineering design. Basic friction angle value is also simply derived from tilt tests with particular samples types and arrangement. But, for the Crocker formation fine sandstone, the value of basic friction angle is never been reported by this testing. Then, the proposed tilt testing approach from literature was conducted to prove and estimate the most suitable samples and arrangement of tilt testing and friction angle value for engineering structures and design in Crocker formation fine sandstone. Results from this study shows that square base slabs with 50mm x 50mm x 20mm dimensions is the most suitable samples and arrangement of tilt testing and basic friction angle, ϕ_b value for the Crocker Formation fine sandstone is 24^o.

Keywords; Basic friction angle, Tilt testing, Crocker Formation, Joint strength, Stability analysis

I. INTRODUCTION

Discontinuities usually found in rock masses as a natural feature and commonly rough or typical irregular roughness. Frictional properties along discontinuities within rock masses control the resistance of natural rock slope to sliding. So estimates of friction angle along discontinuities are necessary to evaluates stabilities of rock slopes. Parton (1966) demonstrated that shearing resistance along discontinuities consisted of two components, a frictional resistance between two sawn surface of rock represented by the basic friction angle, ϕ_b, and a topographic component represented by the roughness angle along discontinuities.

The basic friction angle is an essential input in estimating the shear strength of joints in stability analysis of rock slopes and underground excavations, and in the assessment of factors of safety of a number of failure mechanisms in rock engineering design expect when the rock had been

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softened and altered or when the discontinuity had been polished by displacement.

Barton (1976) estimate of shear strength at low normal stresses where shear displacement is due to sliding along the inclined surfaces. At higher normal stresses, the strength of the intact material will be exceeded and the teeth will tend to break off, resulting in a shear strength behavior which is more closely related to the intact material strength than to the frictional characteristics of the surfaces (Intan Nur Mardia & Mohd For, 2013). Barton and co-workers (Barton & Choubey 1977; Barton & Bandis 1982) analyzed the peak strength, τ behavior of natural unfilled rough joints starting from the basic friction angle of a planar rock joint ϕ_b, a roughness index, JRC, the strength of rock in the joint, JCS and the normal stress, σ_n to which the joint is submitted according to the well-known expression:

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

where
ϕ_r = Residual friction angle (°).

Remark that JRC and JCS are parameters usually evaluated during field characterization of rock masses. A scale-correction is needed when analyzing the behavior of large joints. Since rock joint surfaces are frequently not fresh but weathered, the residual friction angle should be used in Equation 1. It can be estimated according to equation 2 and for planar rock joint surface ϕ_r can be replace by ϕ_b.

$$\phi_r = (\phi_b - 20^o) + 20\,(r/R) \qquad (2)$$

where
r = Schmidt hammer rebound number recorded for a weathered and wet discontinuity, such as those normally found in the field
R = Schmidt hammer rebound number recorded for unweathered surfaces of the same rock.

Basic friction angle, ϕ_b can be determine by the Triaxial test, uniaxial compressive test and direct shear test but sometimes can be limited, time consuming and quite expensive. The chippers and simples method to determine the basic friction angle, ϕ_b is using tilt testing.

The value of ϕ_b for sedimentary rocks that had been calculated in the laboratory from tilt tests and from direct shear tests on fresh planar surfaces found from literatures are 25-37^o as shown in Table 1.

The founded methods to perform tilt tests are proposed by Coulson (1972), Stimpson (1981) for limestone, Bruce *et al.* (1989) for dolostone and quartzite and Cruden & Hu (1988) by using cylinder-shape sample placed over other two equal-dimension cylinder-shaped samples and others, but they do not provide full indications for normalizing tilt testing.

Table 1. Basic friction angle of sandstone (recovered by Alejano *et al.* 2012)

Rock type	Wetness	Basic friction angle, ϕ_b (^{o})	Reference
Sandstone	Wet	26–35	Patton (1966)
Sandstone	Dry	25–33	Patton (1966)
Sandstone	Wet	29	Ripley & Lee (1962)
Sandstone	Wet	31–33	Krsmanovic´ (1967)
Sandstone	Dry	32–34	Coulson (1972)
Sandstone	Dry	31–34	Coulson (1972)
Sandstone	Wet	33	Richards (1975)
Sandstone	Wet	25-35	Barton & Choubey (1977)
Sandstone	-	37	Grasselli (2001)

The Stimpson (1981) approach is then tested by Alejano *et al.* (2012) as well as using various rock lithology's (slate, granite, magnesite and amphibolite) and sample types and arrangements in order to obtained the most suitable methods of reliable basic friction angle value for planar joints to combine with Barton's results for the shear strength of natural unfilled planar joints. The basic friction angle was estimated by using;

$$\phi_b = \text{Tan}^{-1}[(2/\sqrt{3})\ \text{Tan}\ \beta] \qquad (3)$$

where; β - inclination of the set-up at the moment of sliding.

The sample types and arrangements for tilt testing by Alejano *et al.* (2012) are shown in Figure 1. These are:

a) Cylindrical sample longitudinally cut (Figure 1a).
b) Square base slabs samples (Figure 1b).
c) Stimpson type test (Figure 1c).
d) Disc-like samples (Figure 1d).

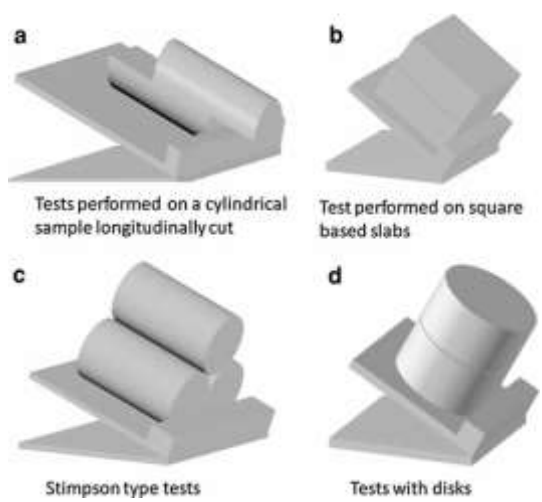


Figure 1. The sample types and arrangements for tilt testing by Alejano *et al.* (2012).

Alejano & Muralha, (2014) perform the tilt test to evaluate the friction angle value and the effect of number of tilting by using Alejano *et al.* (2012) sample types and arrangements, as well as to compare with pull testing result. Perez-Rey (2015) examines the effect of time and wear on the basic friction angles of magmatite, serpentinized dunite, granite and sandstone. Rasyidah Moneey *et al.* (2015) determine the basic friction value of Sandakan Formation's sandstone by tilt testing with square slab sample type with 50mm x 50mm x 20mm dimensions. Bo-An Jang (2016) is also conducted tilt test to determine the basic friction angles for the Hangdeung granite form Korea and Berea sandstone, USA.

The previous experimental study of tilt testing was concluded as follows;

a) Basic friction angle are controlled by rock porosity and by individual grain if the grain size of the lapping compound was appreciably less than grain size of the rock (Coulson, 1972).

b) The ϕ_b values for sedimentary rocks seemed to be very high (and therefore nonconservative) in comparison with values reported in the literature (Alejano *et al.,* 2012).

c) Stimpson (1981) approach identified that sliding behavior on generatrixes is different from sliding behavior on planar surfaces and apparently overestimated ϕ_b when compared with results suggested in the literature. The mechanisms of sliding of three core sticks cause a slight wedging problem, and exaggerate ϕ_b because the normal stress is greater than the shear stress applied (Alejano *et al.,* 2012).

d) Testing using small specimens are also not recommended, as problems may arise related to the curvature of the cut surfaces, then small square slabs samples with 25mm x 25mm x 10mm dimension is not recommended (Alejano *et al.,* 2012).

e) Tests in lengthwise cut cylinder specimens (d = 54mm and l =108mm) and slabs measuring 100 mm x 100 mm x 40 mm provided more reliable results. But it is suggested to use rock slabs with at least 50 cm^2 surfaces and a length to height ratio of at least 2 (larger length to height ratios would be even more favourable), in order to use a large enough tilt surface and to assure that contact stresses are compressive when sliding occurs (Alejano *et al.,* 2012).

f) Disc-shaped samples cut from drill cores (d = 54mm and h = 27mm), not recommended, since they have small surfaces and they do not usually fulfill minimal stress distribution conditions (Alejano *et al.,* 2012).

g) Friction angle derived from tilt test reflect condition of surface wear, finish, weathering and presence/nature of debris (Hencher, 2012).

h) Tilt tests as proposed by Stimpson (1981) can produce reasonable estimates of the basic friction angle if the correct equation is used. Tilt tests and pull tests produce comparable sliding angle results (Alejano & Muralha, 2014).

i) The basic friction angle decreases (increase) if dust is (not) removed after each performed test within a series and as the average value of the 5 first tilt tests performed on recently saw-cut specimens of appropriate dimensions (Alejano & Muralha, 2014).

j) Fourth supplementary repetition should be performed are recommend but a relevant decrease of the friction angle can be observed after repeated tilt-testing due to wear of the surfaces (Alejano *et al.,* 2012 & Perez-Rey *et al.,* 2015).

k) A basic friction angle is proposed as the value of the logarithmic fit evaluated at the corresponding distance for the first test (Perez-Rey *et al.,* 2015).

l) The basic friction value of Sandakan Formation's sandstone is 25^o-35^o but difference and suitable sample type are recommended (Rasyidah Moneey *et al.,* 2015).

m) Basic friction angle on planar surface is decrease by the usage of polishing powder (Bo-An Jang, 2016).

Kota Kinabalu is underlain by the Late Eocene-late Early Miocene Crocker Formation and experiencing rapids urbanization process which involving the utilization of the hilly area. Then, the slope instability problem have been raised due to improper rock slopes cutting and protection measures by inaccurate friction angle, ϕ value in determining safety factor for slope design of the underlying Crocker formation's sandstone.

Due to lack of available basic friction angle, ϕ_b value for the Crocker formation's fine sandstone, this study has been conducted,

i. To determine the most suitable tilt testing samples and arrangements.

ii. To determine the reliable values of ϕ_b.

II. MATERIALS AND METHOD

Generally, the methodology of this study consists of field study, laboratory study and data analysis. Field study includes geological mapping and rock sampling. Thin section preparation, petrographic study, rock core samples preparation and tilt testing are conducted in laboratory study. Data analysis is involving the evaluation and analysis of laboratory data.

There are two types of rock samples collected for this study. The first is hand samples for petrographic study and the second is rock blocks (at least 15mm x 10mm x 20mm dimension) for core samples and tilt testing. Samples of fine sandstone were prepared in the form of fresh clean sawn surfaces obtained using a diamond core bit and saw.

The samples were cut with perfectly straight by carefully preparing and using sufficiently large slabs to come out complete contact. Occasionally, the contact occurs in a small zone in such a way that the upper slab rotates around an axis located in the center of the reduced contact zone.

In order to perform all these tests in a more rapid and accurate way, a special machine was devised, designed and built for this task. It consisted simply on a plane tilting surface which is softly inclines by means of a manually rotated button. The constructed machine is shown in Figure 2.

During the test, the inclination of the samples increases until the one on top begins to slide under its own weight (Chryssanthakis, 2003).

Figure 2 Modified Matest tilt test machine (Cod: A122-10).

Based on the previous comment and recommendation for tilt testing, four (4) samples types and arrangements and sample ID are set-up for this testing as bellows and illustrated in Table 2 and Figure 3.

a) Stimpson type - cylindrical sample with one sliding over the other two with contacts in two generatrixes (Figure 3a)

b) Square type - test performed on square base slabs (square) with 50mm x 50mm x 20mm dimensions (d = 54mm and h = 108mm) (Figure 3b).

c) Cylindrical type - tests performed on a cylindrical sample longitudinally cut (d = 54 mm and h = 108 mm) (Figure 3c).

d) Disk-like type - tests on disk-like samples (d = 54 mm and h = 27 mm) (Figure 3d).

Table 2 Used sample ID for this tilt testing.

Sample type	Equal-dimension cylinder-shaped	Square base slabs	Cylindrical sample longitudinal	Disc-like
Used sample ID	Stimpson	Square	Cylindrical	Disc

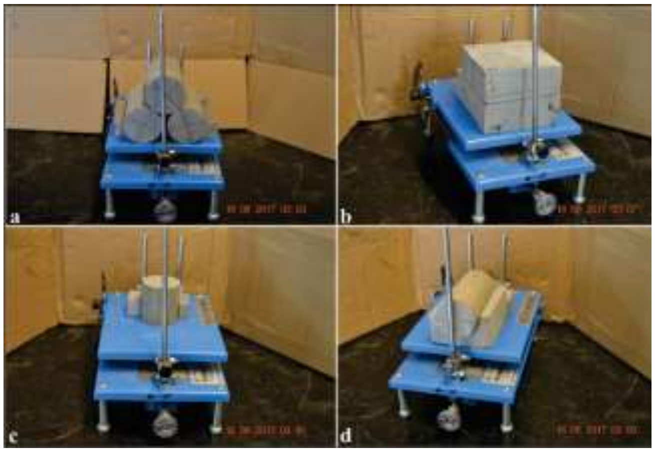


Figure 3 Different set ups for the tilt tests.

The selection of Stimpson, cylindrical and disc types of tilt testing samples and arrangement are only to compare and evaluate the results of basic friction angle values and sample rotation during tilting progress.

The procedure described below was used for all the tests with the tilting machine and the horizontality was confirmed each time using a bubble level. A detailed description of the procedures used for performing each of the tests as follows.

a) The specimens were cut according to the indicated dimensions using diamond core drill bits and saws.

b) The lower specimens were placed on the plane-tilting platform in the horizontal position and secured in place (for the Stimpson tests, both lower cylinders were secured).

c) The upper specimens were placed on the fixed specimens in the horizontal position (for the Stimpson a test, the upper cylinder was placed horizontally on the other two specimens and generatrixes were marked for the repetition tests).

d) Tests were performed in both directions for lengthwise-cut specimens or cylindrical sample longitudinally cut.

e) All the samples are marked to monitor the movement and rotation during tilting process.

f) The platform was progressively tilted at the rate of 0.4 mm/s until the upper specimens began to slide, and the tilt angle of the platform was recorded. Only tests corresponding to displacements of at least 10 % of the sample length were taken into account.

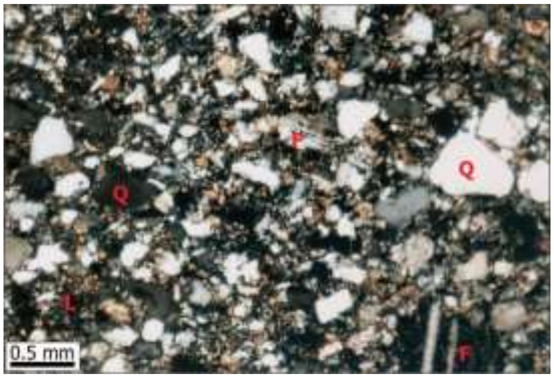
g) Each test was repeated for five (5) times. The surface was wiped with a dry cloth between each repetition and specimens were placed in the same initial positions.

h) Results were calculated as the mean of the results for all the repetitions of each test.

III. RESULTS AND DISCUSSION

Petrographical study is based on the mineralogical composition of Pettijohn (1975) classification and shows that the sandstone is classified as fine lithic wacke. Photomicrograph 1 shows the appearance of this rock under cross polarized light (XPL) view.

Results of the tilt testing are showing in Table 2 and Figure 3. The results are very different (Table 2). The Stimpson, square, cylindrical, and disk types yielded basic friction angle values range 26°-31°, 21°-30°, 26°-29° and 29°-31°, respectively.



Photomicrograph 1 Fine lithic wacke under cross polarized light (XPL). Note: Q-Quartz; F-Feldspar; L-Lithic. *Note*: Disp.- displacement

Table 2 Value of friction angle and displacement.

Sample type	Stimpson	Square	Cylindrical	Disc
Average Friction Angle (o)	29	24	28	31
Disp. (%)	0	23	25	83

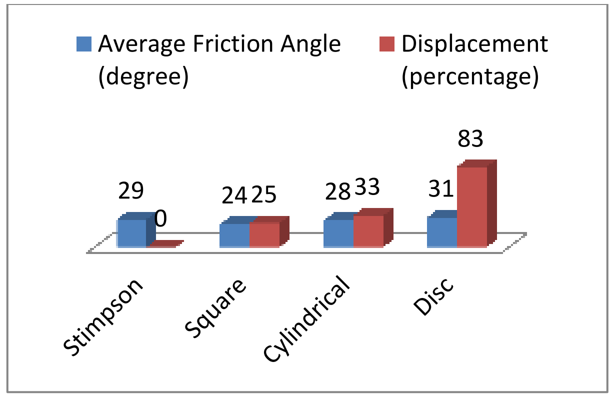


Figure 3 Different set ups for the tilt tests.

The average basic friction angle yielded by square samples is 24° and considered as the lower and most reliable value. The basic friction angle is lower than conventional 30° for estimation of shear strength of joint and factor of safety. The Stimpson, cylindrical and disk types are calculated for 29°, 28° and 31°, respectively in average of ϕ_b which considered as high and not reliable value. The Stimpson type is high in friction angle because the mechanisms of sliding of three core sticks cause a slight wedging problem as stated by Alejano *et al.* (2012).

Square type is also had wide surfaces and fulfill minimal stress distribution conditions that deriving reliable force to move. Minimal stress distributions conditions are also not fulfilling by the others three types which have causing higher value of basic friction angle.

Displacements of samples in tilting proses are also very different for all samples. The Stimpson, cylindrical, square and disk-like samples are recorded for 0, 23, 25 and 83% of rotation or displacement. No displacement for Stimpson samples in the process of progressively tilting because of sliding behavior on generatrixes. Displacements have been occurred due to small curvature of the cut surface but decrease for larger specimen such as square samples with 50mm x 50mm x 20mm dimensions.

The square and cylindrical samples dimension had been fulfilled the stress criteria as state by Muralha (1995) which allowing only low displacement or less rotation during tilting process. The lower displacement between these two samples led to the selection to square sample for more reliable value. The tests on the disc-like samples failed to fulfill the criteria because most of the representative points appear under the discontinuous line $l/h = 4 \tan \phi_b$, then cannot be considered as fully reliable.

IV. SUMMARY

Based on this conducted tilt testing, it is concluded that:

a) The most suitable samples and arrangement is square base slabs (square) with 50mm x 50mm x 20mm dimensions.

b) The basic friction angle, ϕ_b for Crocker Formation fine sandstone is 24^o.

V. ACKNOWLEDGEMENTS

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