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The basic frictional resistance of sheeting joints in Hong Kong granite

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Introduction

This paper presents the results of a series of direct shear tests carried out on samples taken from sheeting joints in Hong Kong Granite. The tests formed part of a study into the stability of rock cut slopes in the North Point area of Hong Kong. The study was carried out by Golder Associates on behalf of the Building Ordinance Office of the Public Works Department.

It is hoped that this paper will provide useful guidance on the basic frictional strength of these particular rocks, and that the method of interpreting results discussed here will lead to the adoption of better practice in Hong Kong.

Sampling

Samples for shear testing were taken from HQ size diamond drill core obtained using an air-foam flushing technique. Both vertical and horizontal holes were drilled and the orientation of intersected joints determined by means of an impression packer. Samples of sheeting joints were selected with the aim of obtaining a full range of weathering conditions from fresh to completely decomposed. Testing was undertaken at the PWD Laboratory at North Point. Prior to testing, the samples were stored in a 'wet' room to maintain the field moisture conditions.

Testing method

The majority of tests were carried out using a direct shear box designed by Golder Associates and illustrated diagrammatically in Figure 1. A few tests on saw-cut samples and on intact weak material where excessive dilation or tilting was not expected were carried out using a standard Wykeham Farrance soil shear box. The Golder

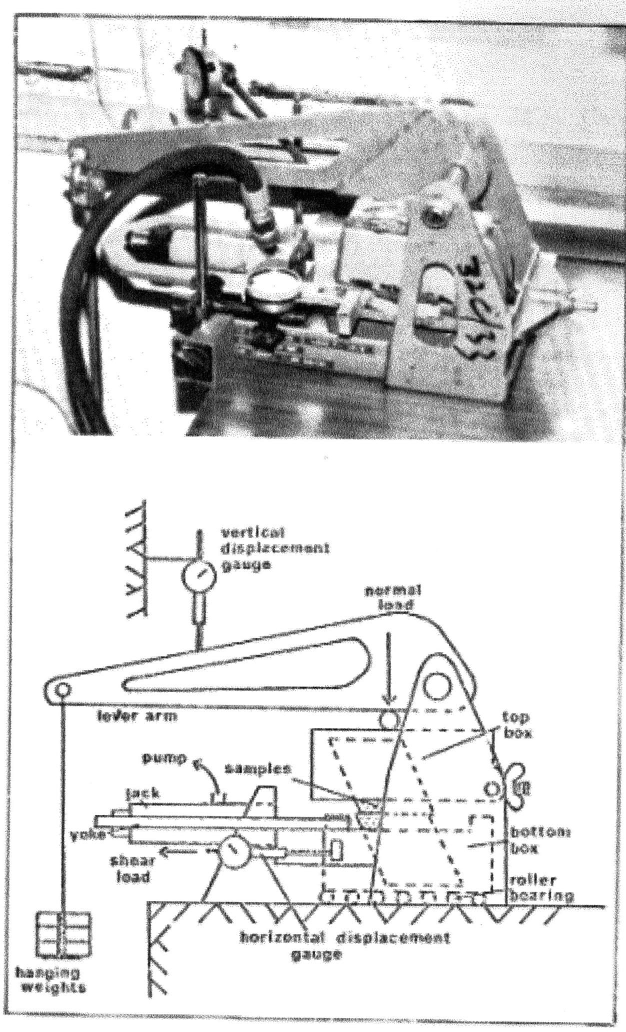


Fig. 1 Golder Associates direct shear box

Associates shear box is designed to allow testing at the relatively low stresses that are generally applicable to rock slope design. Normal load is applied through a hanging weight system and shear load by a hydraulic jack. Displacement gauges allow the measurement of vertical and horizontal movements during the test.

A multistage testing technique was adopted to allow the determination of shear strengths at various stress levels for single samples. In this method each stage is carried out by applying a given normal load and then gradually increasing the shear load until a 'peak' strength is achieved. The normal load is then changed and a further 'peak' strength obtained. With this technique, true peak strength is obtained only for the initial stage of testing. Subsequent runs may have reduced shear strengths in comparison with virgin peak strengths. It is usual in multistage testing to use progressively increasing normal loads. Where significant losses of peak strength are suspected, the effect may be quantified by testing similar samples under decreasing normal stresses. The maximum strengths achieved at the highest normal loads may then be compared and it will be seen if the sample loading history is affecting the results. Depending on the amount of horizontal strain, samples may be reassembled in the zero displacement position at the change of normal load or may continue from the point at which the previous stage ended. Where samples are reset, the rock flour produced by the initial shearing should be removed.

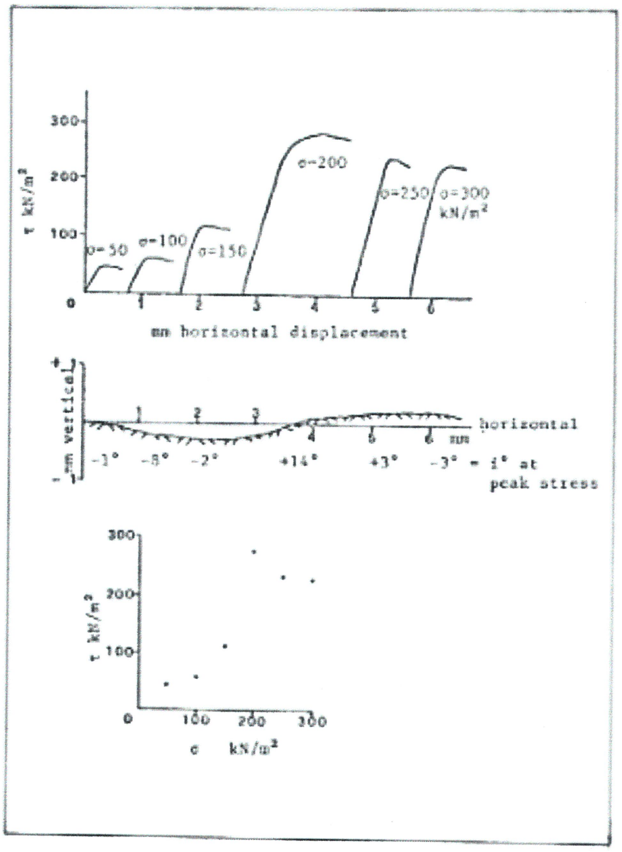


Fig. 2 Uncorrected data from a multistage test

The majority of tests were conducted with the rock joint under water. The purpose of this was to assess possible changes in strength as water will induce lubrication as well as pressure effects in some rock types (Brown et al, 1977).

A number of tests were carried out on saw-cut surfaces of slightly decomposed and moderately decomposed granite to provide reference values of basic shear strength for flat surfaces.

Samples preparation and description

Each sample was trimmed with a diamond saw and then cast into the two halves of the shear box using dental plaster. Considerable care was taken to align the joint plane as closely as possible with the shearing plane of the machine.

Close examination and description of the surfaces were made both before and after testing. Before testing, special note was made of areas likely to come into contact during sliding. After testing, attention was focussed on the nature of any visible damage. Profiles of each sample were recorded using a needle profilometer. For record purposes, high quality photographs were taken using low angle lighting to emphasize relief. Photographs were also taken using vertical electronic flash, the high reflectance of rock flour clearly indicating areas of damage. Thin sections were made of a number of specimens and these were described using a petrological microscope.

Shear strength criteria

The shear strength of rock joints is generally expressed as a Coulomb relationship, i.e.

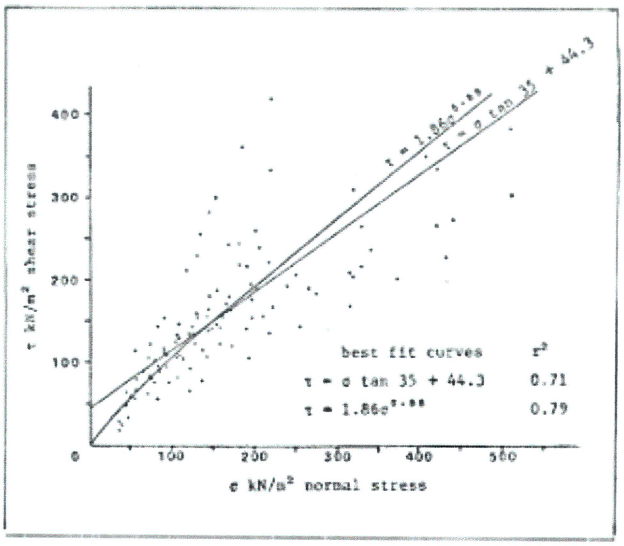


Fig. 3 Uncorrected data – natural surfaces

$$\tau = c + \sigma \tan \phi$$

where τ, c, σ and φ are shear strength, cohesion, normal stress and friction angle respectively. For natural rock joints, this is generally applicable only within a limited range of normal stresses.

A more generally applicable criterion is the bilinear model. At low stresses, overriding rather than shearing occurs and

$$\tau = \sigma \tan (\phi + i)$$

where i is the roughness angle. At higher stresses, the roughness features are sheared through and

$$\tau = c + \sigma \tan \phi$$

where c is an apparent cohesion defined by the intercept on the shear strength axis.

A continuous mathematical function which approximates the above bilinear model is the power law

$$\tau = a\sigma^b$$

where a and b are constants.

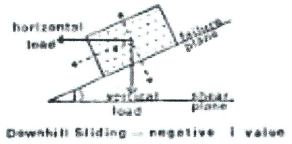
The relationship that best describes a set of data can be established by statistical means using the method of least squares. A measure of correlation is described by the function r^2. If r^2 is 1 there is perfect correlation (i.e. all points lie exactly on the given line). For $r^2 = 0$ correlation is non-existent.

Uncorrected test results

Initially, the raw test data were presented in graphical form as illustrated in Figure 2. For each stage of testing, shear stress and vertical displacement were plotted against horizontal displacement as in Figure 2a and 2b. In addition, peak shear stress was plotted against normal stress for each load stage (Figure 2c).

Normal and shear stresses were calculated from the normal and shear loads divided by the gross area of contact. The contact area was adjusted to take account of horizontal displacement.

Data presented as in Figure 2c incorporate the effects of roughness as well as errors in setting the joint horizontally in the shear box. The measured angle of shearing resistance is directly affected by vertical movements of the upper specimen from either of the above causes. Referring



$$\tau = \frac{\text{horizontal load}}{\text{gross contact area}}$$

$$\sigma = \frac{\text{vertical load}}{\text{gross contact area}}$$

shear stress along failure plane

$$\tau_i = (\tau \cos i + \sigma \sin i)\cos i$$

normal stress across failure plane

$$\sigma_i = (\sigma \cos i - \tau \sin i)\cos i$$

Reverse signs for positive i value

Fig. 4 Stress corrections for vertical movement

to Figure 2, it can be seen that an anomalously high strength occurs at a normal stress level of 200 kPa. The reason for this is clearly shown on the vertical displacement graph (Figure 2b) where it can be seen that this loading stage coincides with the most steeply inclined roughness feature.

Figure 3 is a summary plot of the North Point data in its uncorrected form. It is difficult to interpret this data meaningfully because of the wide scatter in the results. Unfortunately, it appears to be common practice in Hong Kong to present shear test data in this manner. If vertical dilation measurements have not been taken (also unfortunately common) the results may be quite misleading.

Corrected data

A more meaningful way of presenting the data is to normalize it to a common horizontal and planar surface by resolving stresses to take account of dilation, as in Figure 4. By doing so, all data is made to represent, effectively, the shear strength of a naturally textured and planar surface. The effect that roughness will have on field shear strength can be considered quite separately by field measurements once the normalized strength has been determined.

Corrections for dilation should be made at peak shear stress. It is generally not adequate to take an average angle over a complete run or to use an angle measured from a surface profile which might not reflect actual test behaviour. Very careful laboratory work is required to obtain correct displacement measurements as significant dilational changes may occur very rapidly as the peak strength is reached.

The corrected data for the North Point study is presented in Figure 5. Clearly the amount of scatter is considerably reduced from that in Figure 3. By removing the highly variable effects of surface roughness, it can be seen that the basic frictional behaviour of the joint materials is quite consistent for all the tests performed.

Discussion of laboratory test results

Direct shear tests were carried out on 17 natural joint samples ranging from rough almost fresh, to highly decom-

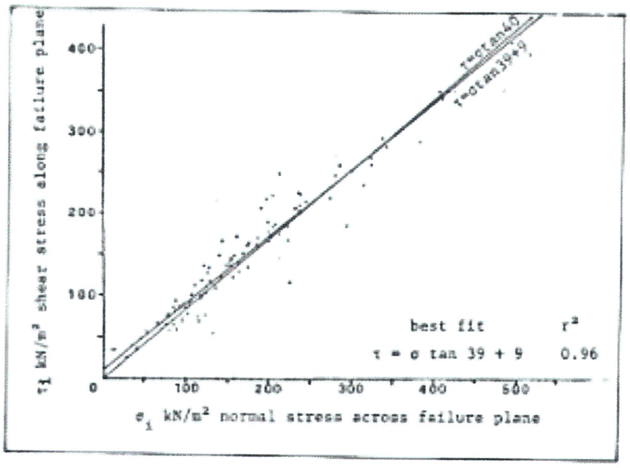


Fig. 5 Corrected data – natural surfaces

posed granite. A number of joints were heavily coated with iron and manganese oxides, several had accumulations of clay, and a single joint had slickensided surfaces. One test was carried out on a joint with a thick layer of kaolin between moderately decomposed granite.

Despite such variation in mineralogy and weathering, the normalized results were remarkably uniform and for all practical purposes a basic friction angle of 40 degrees can be taken for all weathering grades. Cohesion intercepts in these tests were generally small. Laboratory values of 'cohesion' for rock joints are usually inapplicable to engineering analyses since it is not possible to test joints with surface roughness features which are representative of field conditions. Small scale tests should be used only to assess the basic friction angle ϕ. Field observations are needed to evaluate rock joint 'cohesion' which is mainly a function of surface roughness rather than true cohesion in the same sense as soil shear strength. Details of individual tests are given in Table 1.

Results from tests carried out under water were not significantly different from those obtained from dry tests and all data is included in Figures 3 and 5.

Tests on saw-cut surfaces gave friction angles of 34 and 38 degrees for slightly and moderately decomposed granite respectively. These lower strengths reflect the artificially smooth surfaces obtained by grinding.

Field strength of sheeting joints

Because of the size of laboratory samples, direct shear tests will incorporate only the effects of small scale roughness features. The above procedure shows how laboratory tests may be normalized in terms of a common planar surface.

Measurement of roughness in the field may be performed by a variety of techniques and some of these will be discussed in a subsequent paper. Field shear strength is generally assessed as a combination of basic frictional strength plus an appropriate roughness angle (depending on the scale and nature of the problem). Special consideration has to be given to joints with thick decomposed zones, where the roughness component is no longer applicable.

Conclusions

Normalized data from direct shear tests on sheeting joint samples from Hong Kong Granite give a friction angle of 40 degrees. This value is for planar but naturally textured

Table 1 Direct shear test results

Rock Grade	Joint Description	Failure Type	Test Conditions	Corrected Strength	Stress Range kPa
II	Hard surfaces. Some chloritisation.	Fine rock flour. Flaking and crushing of weaker material.	under water	$\tau = 2.5 + \sigma \tan 38°$	0-220
II	Hard surfaces coated with secondary quartz.	Fine rock flour and grooving.	not saturated	$\tau = \sigma \tan 37°$	0-400
II - III	Planar. Thin oxide film over 40% of surfaces. Hard.	Local shearing of asperities. White flour.	not saturated under water	$\tau = \sigma \tan 40°$ $\tau = \sigma \tan 42.5°$	0-150 0-240
II - III	Step feature due to cross joint.	Wear in decomposed rock.	not saturated	$\tau = 10 + \sigma \tan 40°$	0-320
II - III	50% Fe, Mn oxides. Cross joints.	Shearing decomposed rock. Smearing oxides.	not saturated	$\tau = \sigma \tan 39.5°$	0-285
II - III	Undulating. Covered with Fe oxides.	Grooving in Fe oxide and underlying rock at higher stresses.	not saturated	$\tau = 20 + \sigma \tan 34.5°$ $\tau = \sigma \tan 46.5°$	0-140
II - III	Fe oxides and clay on part surface.	Shearing of surface materials.	not saturated	$\tau = \sigma \tan 42°$	0-240
III	Fe, Mn oxides on surface.	Fine flour. Some ploughing.	under water	$\tau = \sigma \tan 40°$	0-770
III	Some clay infill. Fe oxides.	Little damage. Fine flour, loose grains.	not saturated under water	$\tau = 14 + \sigma \tan 38°$ $\tau = \sigma \tan 47°$	0-150 0-200
III	60% covering oxides. Hard asperities	Fine flour from wear of asperities	under water	$\tau = 15 + \sigma \tan 38.5°$	0-590
IV	Friable. Covering of oxides.	Shearing through weathered rock.	not saturated	$\tau = \sigma \tan 40°$	0-250
IV	Friable. Covering of oxides.	Shearing of surface materials & some ploughing.	underwater	$\tau = 10 + \sigma \tan 40°$	0-200
IV	Iron stained decomposed granite.	Loose rock flour.	under water (Wykeham Farrance Box)	$\tau = \sigma \tan 40°$	0-280
IV	Highly decomposed granite.	Zone of shear through weak material.	under water	$\tau = \sigma \tan 41.5°$	0-190
IV	Highly decomposed granite. Slickensided.	Specimen collapsed on dismantling test.	under water	$\tau = \sigma \tan 42°$	0-440
IV - V	Intact sample with relict joint. Friable.	Tested intact. Zone of shear. Above 169 kPa, specimen collapsed.	under water	$\tau = 20 + \sigma \tan 42.5°$	0-160
-	Kaolin infill between moderately decomposed rock.	Softening/ remoulding of kaolin. Compression occurred throughout test.	under water	$\tau = 20 + \sigma \tan 35.5°$ with no correction for compression $\tau = 10 + \sigma \tan 27°$	0-380

surfaces. Tests on saw-cut surfaces give values less than this.

The above value may not be applicable outside the North Point study area. It would not be prudent to use these results outside this context without prior and detailed validation.

Acknowledgements

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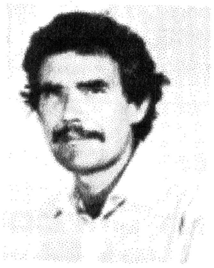
Authors



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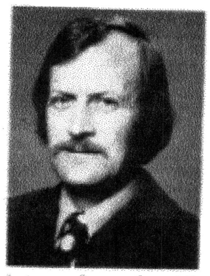
In 1976 he joined W.S. Atkins and Partners in the UK and in 1980 came to Hong Kong to work for the Geotechnical Control Office. He has wide geotechnical experience ranging from piling to seismic risk analysis. In Hong Kong he has been working on geotechnical studies of proposed development areas and is currently involved in an empirical study of Hong Kong's slopes.



Dr. L.R. Richards obtained his civil engineering degree from the University of Auckland and worked with the Ministry of Works in New Zealand on a number of major highway and airport projects.

He went to the UK in 1971 to undertake Master's and doctoral research at Imperial College on the shear strength of joints in weathered rock. In 1974 he joined Golder Associates when the UK office was being set up and is now Group Vice President responsible for the company's geotechnical and mining activities in the UK, Europe, Africa, Asia, Middle and Far East. His major project experience includes underground pumped storage schemes in the UK and Ireland; mining projects in Ireland, Turkey, Canada, Spain, and Namibia; slope stability and foundation studies in the UK and Hong Kong.