THE LABORATORY DIRECT SHEAR TEST — AN ANALYSIS AND GEOTECHNICAL EVALUATION

L'ESSAI DE CISAILLEMENT DIRECT — ANALYSE ET ÉVALUATION GÉOTECHNIQUE

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Summary:

The direct shear test belongs to the standard tests in rock engineering to determine the frictional resistance along rock joints. The test results are greatly influenced by the choice of test parameters. The influence of individual parameters like normal stress, shearing rate and shape and size of the sample on the friction behaviour of rock joints is shown using material laws and numerical analysis. Recommendations for conducting such tests and for evaluating the test results are made.

Résumé:

L'essai de cisaillement direct fait partie du programme standard des études de Mécanique des Roches pour déterminer la résistance de frottement des dièses de roches. Le résultat expérimental obtenu est influencé substantiellement par le choix des paramètres de l'essai.

Les influences isolées de la tension, de la vitesse de glissement, de la forme et des dimensions de l'échantillon sur le comportement au frottement des fissures des roches sont étudiées à l'aide des lois contraintes-déformations quantifiées et des considérations analytiques. Enfin, on propose des recommandations pour l'exécution des essais et l'évaluation des résultats.

1. Introduction

The determination of rock properties is still associated with many uncertainties. An engineer hardly feels easy in using friction values in his calculations which have been determined in the laboratory. The laboratory peak and residual friction values are, therefore, often reduced to one-half to two-thirds of their measured values. A definite judgement on the desirability of this practice can only be given by comparing the friction coefficients measured in laboratory tests with those determined from back calculation of actual slides. Some guidelines for evaluating laboratory test results can, however, be obtained from an analysis of the laboratory shear test. To this end, the individual parameters and their influence on the test results are discussed in the following sections.

2. Shear strength and frictional resistance

In the shear test a shearing surface is produced in an intact sample and the resistance to shearing is defined as the shear resistance. The frictional resistance is, however, determined on an existing joint surface. It is defined as the resistance against sliding, irrespective of the maximum slope of the dilatation curve (Fig. 2). This value is reached after a small shear displacement. According to the geometric friction law, residual friction is relevant only at points where no dilatation takes place i.e. where the dilatation angle is zero. During shearing the frictional resistance can thus fall below its residual value (Fig. 2). Often the residual value is reached only after large shear displacements.

Abrasion results in the formation of fine rock powder in the joint during the shearing process which changes the residual friction behaviour. This mylonisation in the joint is associated with increasing rounding of the grains and formation of graded layers of fine grains. The shearing surface moves away from the joint into the mylonite material with increasing shear displacement.

For small normal stresses the residual frictional resistance varies more or less linearly according to the COULOMB-NAVIER law. At higher normal stresses the relationship becomes non-linear (Fig. 3). For the normal stress range investigated (up to 100 MN/m²) the strength envelopes of granite and of joints are wide apart so that even in this high stress range the effect of the discontinuity has to be considered.

Even for low normal stresses the peak friction behaviour is not linear. It could be approximately expressed as an exponential function (SCHNEIDER, 1975) and depends upon the dilatation angle i as first proposed by PATTON (1966). Tests on models with rough joint surface geometries have shown that the peak friction decreases not only with increasing normal stress but also with decreasing material strength (Fig. 4). The same joint surface geometry in models brings about complete agreement of the test results with the envelope. In friction tests on natural rock joints, however, the peak friction values varied because of different geometries and mean values had to be adopted in this case.

4. Influence of the joint size

Influence of the size of the shearing surface on friction for the same joint surface geometry, as observed by LEICHTNITZ (1976) on plaster cast models, is shown in Fig. 5. The maximum size of the samples was 432 cm². The next smaller size was obtained by dividing the larger samples into two equal halves which were tested separately. The friction values obtained from the largest samples are reasonably
5. Influence of restrained dilatation

Friction tests are normally conducted under constant normal stresses i.e. under restrained dilatation on the joint. Cases may often arise where the friction behaviour must be determined under restrained dilatation, as in the case of a set of rock layers, surrounded by rock mass, trying to slide into a rock cavity. The dilatation along joint surfaces is restrained here by the surrounding rock mass and leads to a proportional increase in the normal stresses and thus to an increase in frictional resistance.

The influence of restrained dilatation on friction could be demonstrated very clearly in tests conducted on models of natural bedding planes with ripples (Fig. 6). In tests with constant normal stress, i.e. unrestrained dilatation, the friction curve follows the ups and downs of the dilatation curve along surface ripples. With a normal stiffness of 1.72 MN/m², which is about 1/4000 of the rock modulus, the friction and dilatation behaviour hardly shows any influence of the restraint. Increasing the normal stiffness to about 1/40 of the rock modulus results in substantial decrease in the dilatation (vertical displacement h). The tangential and normal stresses, however, increase only about 10 % above the corresponding values in tests with constant normal stress. The restraint has two opposite effects: it leads to an increase in normal stress, and thus also to an increase in friction resistance, but this also increasingly results in the shearing of asperities in the shear plane which in turn leads to a decrease in dilatation (h). High normal stiffness of about half the rock modulus leads to a noticeable increase in the friction resistance.

6. Influence of shearing rate

The shearing rate in a test should be chosen considering the practical problem where the results are to be used and the deformability of the rock to be tested. Tests on Opalinus clay, a weak claystone, show a distinct increase in frictional resistance with increasing shearing rate (Fig. 7). The tangential stress-displacement curves can be divided into a linear part, which is termed shear stiffness (after GOODMAN, 1972), and in a non-linear visco-plastic part. For a definite shear displacement a linear relationship between shear resistance and logarithm of shear rate is obtained (Fig. 8). The influence of shear rate increases with increasing normal stress. For different total displacements the frictional resistance-shearing rate relationship is identical. The frictional resistance can thus be formulated as a function of time as well as of linear displacement (SCHNEIDER, 1977) (Fig. 9). The calculated time-displacement curves show that even a small change in shear stress can change the creep behaviour substantially.

Time-consuming and technically cumbersome creep tests can be avoided and substituted by strain-controlled friction tests provided the test set-up permits sufficient variation of the strain rate.

All rocks do not show such pronounced time-dependent friction characteristics as observed in Opalinus clay. This is particularly true for "brittle" rocks. In tests on granite for example, the friction behaviour is strongly affected by the mylonitisation process in the joint that no time dependence could be observed within the range of strain rates (1 : 20 000) used. Rock types such as weak sandstone with clay, binder, limestone, marl and clayshales could be considered to indicate the limit for which the influence of strain rate can be observed in laboratory tests.

7. Force transmission and stress distribution in a test sample

The external forces should be applied on the sample, i.e. on the shear frame, as far as possible, without producing moments. The schematic diagram in Fig. 10 shows how these forces are then transmitted from the stiff shear frame to the sample, particularly to the joint surface. The sample has a longer lower portion as compared to the upper portion. The normal force N produces an average normal stress a, (or a >), which is transmitted through the upper and lower frames as shear stress τ (or τ >). Both a and τ contribute moments to the sliding plane which should be balanced by the moment caused by ± τ. These highly simplified concepts are meant only as an explanation. The results of a finite element analysis, though only two-dimensional, can describe the prevailing conditions in a better way (Fig. 11). The lines of maximum shear and corresponding compressive stresses show large stress concentration mainly on the side boundaries of the sample, which confirm the above concepts regarding the transmission of the tangential forces. The normal and shear stress fields in the middle portion of the sample are, however, homogeneous.

The normal and shear stress distributions in the joint elements illustrate the above fact more clearly (Fig. 12). The curves were obtained for different load cycles in which the normal force was kept constant and the shear force was successively increased. High stresses develop near the ends of the sample whereas in the middle portion the stresses are uniform. The stresses compare very favourably with those calculated from the external forces and the nominal contact area as in the friction test.

constant. Decreasing the sample size results in a wider scatter of the friction values, the scatter being nearly 100 % for samples of one-eighth the original size. The results further show that the mean value of peak friction obtained on models of 54 cm² joint surface area is higher than the value for models of 432 cm² surface area. The minimum frictional resistance measured on both sizes was, however, the same.

On the basis of its definition, residual friction is independent of the size of the sample as long as it does not fall below the statistically representative size of the mineral grains.