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A NEW METHOD FOR DETERMINING PEAK FRICTION OF ROCK JOINTS

UNE NOUVELLE METHODE POUR DETERMINER L'ANGLE DE FROTTEMENT MAXIMUM D'UNE FISSURE ROCHEUSE

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Summary:

The paper describes a new experimental set-up for determining the peak friction angle of large rock joints. The method uses the principle of hydraulic resistance of rough surfaces. The hydraulic roughness parameters determined on large rock joints in the laboratory are correlated to the peak friction angle.

Résumé:

La publication décrit une nouvelle technique expérimentale pour déterminer l'angle de frottement maximum d'une fissure rocheuse épaisse. Le procédé utilise le principe de la résistance hydraulique de surfaces rugueuses. Les paramètres qui décrivent la rugosité hydraulique d'une fissure épaisse en laboratoire permettent d'en déduire l'angle de frottement maximum.

As the investigations by PATTON /1966/, RENGERS /1971/ and others have clearly shown, the peak friction of rock joints depends only on the joint surface. PATTON has given the dependence of the shear resistance on the normal stress in the form of a diagram often quoted in the literature. The investigations reported in this paper deal with the experimental determination of the peak frictional resistance of interlocked rock joints under low normal stresses.

Hardly any systematic investigation has so far been made on peak frictional resistance of rocks due to two major reasons:

1/ The influence of the parameter, surface geometry, on the peak frictional resistance under different normal stresses is difficult to investigate because shearing of rock samples in normal shear test apparatus leads to wearing of the surface and thus to a change in the surface geometry.

2/ The size of the rock sample and the location from which it is taken can have an important influence on the measured shear resistance because even a single rock joint can have different surface form and roughness at different points.

It is therefore desirable to test samples as large as possible. The smallest size of the rock samples, above which sensible test results would be obtained could so far only be fixed empirically. For rock mechanics research it is therefore necessary to find ways and means of determining peak frictional resistance on largest possible rock samples in the simplest possible manner. The residual friction, on the other hand, seems nearly independent of the size of the sample. Consequently tests on small rock samples seem sufficient for its determination.

As the peak frictional resistance depends on the surface geometry of the joint it was considered necessary to describe these geometries with the help of surface profiles.

Both RENGERS /1971/ and SCHNEIDER /1975/ have analysed numerous surfaces and have described methods for predicting the shearing behaviour of interlocked joint surfaces from the surface profiles.

Since large scale in-situ tests are cumbersome and very costly we have tried to replace them by simple laboratory tests. A simple experimental set-up /Fig. 1/ was prepared for this purpose through the support of Prof. Dr. Mosonyi at the Theodor-Rehbock-Flussbau-laboratorium of the University of Karlsruhe.

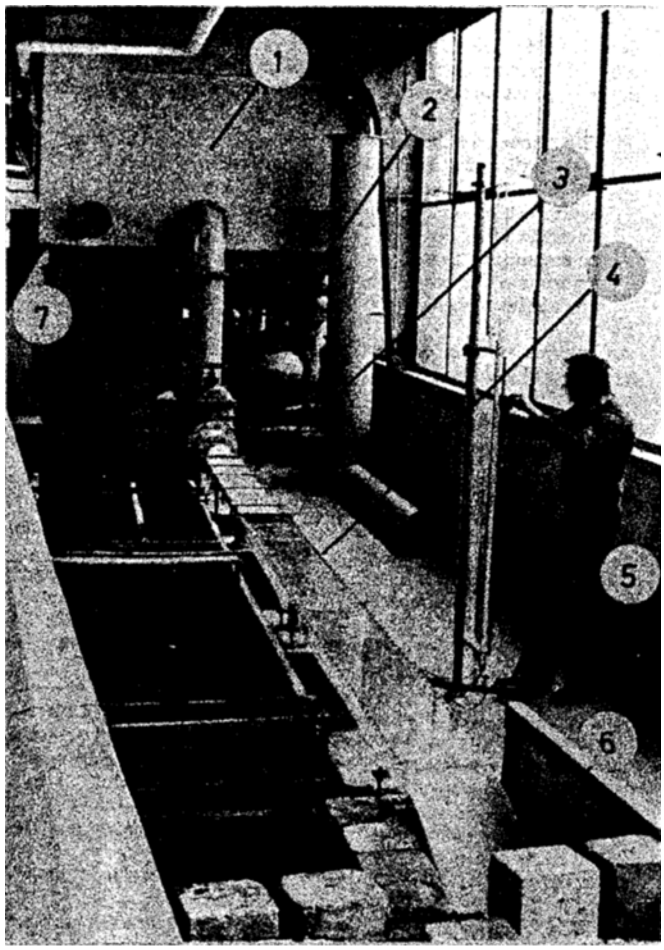

Fig. 1 : Experimental set-up for hydraulic friction measurements
1 = water tank, 2 = throttle valve, 3 = inlet pipe, 4 = measuring pipe, 5 = water manometer, 6 = stilling basin, 7 = measuring weir.

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The test set-up essentially consists of a water tank, throttle valve, inlet pipe and the main rectangular measuring pipe. A water manometer, a stilling basin, and a discharge measuring weir complete the experimental set-up.

A plaster cast imprint of the rock joint serves as the roof of the rectangular pipe whose other three sides are smooth. In place of a shear test on a 4 m long rock sample, water is made to flow in the pipe and the influence of the surface geometry on the hydro-mechanical characteristics is determined.

The constants so obtained, which depend only on the joint geometry, are compared with the mechanical friction constant. This friction constant is described in the literature as "angle of sliding up" and when added to the residual friction angle it gives the peak friction angle.

The initial difficulty to be overcome was the correlation between the hydraulic constants and the mechanical dilatation angle i of the rock surface. Considerations of high costs and technical difficulties made it almost impossible to conduct both shear tests and tests for hydraulic friction on rock samples of large size. We therefore decided to first perform tests on **joint models** whose peak friction angles are known from the tests conducted by PATTON /see Figs. 2 and 3/. Large joint surfaces with such geometries can easily be produced on a milling maching and put in a hydrualic pipe for testing.

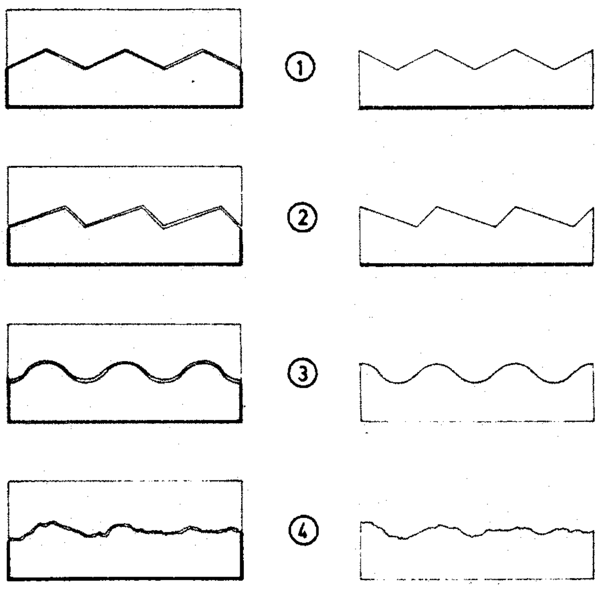

Fig. 2 : Joint models for which sliding up on asperities is possible
1 = symmetrical saw-tooth joint, flat inclination, 2 = unsymmetrical saw-tooth joint, flat inclination, 3 = rippled surface, flat inclination, 4 = cast of a natural rock joint. Upper halves of models on the right.

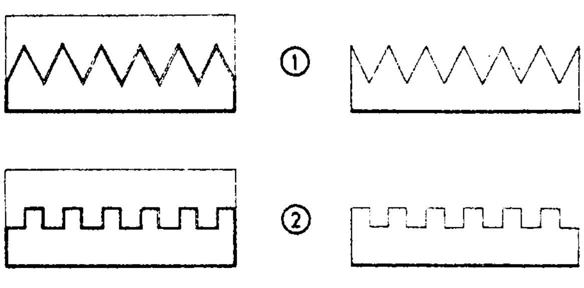

Fig. 3

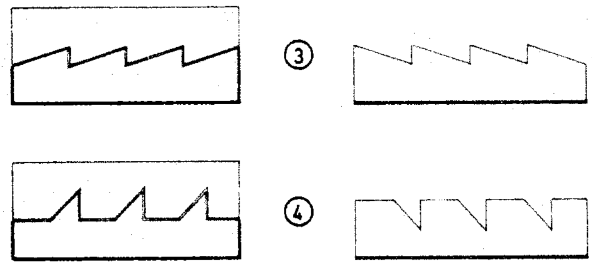

Fig. 3 : Joint models for which sliding up on asperities is either not possible or possible only in one direction
1 = symmetrical saw-tooth joint, steep inclination, 2 = joint profile with rectangular teeth, 3 = saw-tooth joint with a vertical or steep side, 4 = broken saw-tooth profile.
Upper halves of models on the right.

The requirements imposed on the joint model were:

1/ The quotient of the area of the projected surface of all asperities on an imaginary reference plane to the area of the reference plane is always nearly one.

2/ Both joint surfaces have complementary asperities.

3/ The slopes of asperities steeper than 25^{o} were not considered, which is supported by the fact that no shear tests with steeper angles have been described in the literature.

4/ Asymmetric asperities do occur, but have minor influence. Mean differences in inclinations of asperities of up to 1^{o} to 2^{o} are known both from own observations and from the literature.

The hydraulic constants were determined using the method proposed by SCHLICHTING /1936/. Only the basics of the method are mentioned here, which is described in detail in the original paper:

Velocity profiles are measured at different points on the longitudinal symmetry plane in a rectangular pipe with a high width-to-height ratio. The velocity of flow should be so chosen that the Reynolds Number is greater than 10^{5}, so that a fully turbulent flow can be assumed.

The rough roof of the pipe /as mentioned earlier/ produces an asymmetric velocity profile. Since only one surface of the tube is rough there is no influence of the opposite smooth surface. Velocity profile is measured using a Pitot tube /PRANDTL model/.

Beside the velocity profile, the frictional resistance of the pipe to flow of water is determined by measurements of the pressure drop.

Since the shear stresses on the two walls of the tube and the pressure drop should be in equilibrium, one gets the first equation for the shear stresses on the rough and the smooth wall, which is valid for a rectangular pipe with a high width-to-height ratio:

$$\tau_r + \tau_g = b\frac{dP}{dT} \qquad /1/$$

/b = height of the pipe/

If we use the shear stress velocity instead of the shear stress on the wall we can use

$$v_x = \sqrt{\frac{\tau}{\rho}}$$

as given in equation /5/.

The universal velocity distribution law for a smooth wall /PRANDTL/

$$\frac{v}{v_{xg}}\ 5.5 + 5.75 \log \frac{y v_{xg}}{\nu} \qquad /2/$$

can be used for determining the shear stress τ_g on the smooth wall from the measured velocity profile. If one plots the measured velocities against the logarithm of the distance from the smooth wall one gets a straight line

$$v = m_g + n_g \log y \qquad /3/$$

whose inclination n_g is obtained from /2/ and /3/

$$n_g = 5.75\, v_{xg} \qquad /4/$$

or

$$v_{xg} = \frac{n_g}{5.75} \qquad /5/$$

Substituting the velocity so determined and the measured pressure drop in

$$v_{xr}^2 + v_{xg}^2 = \frac{b}{\rho}\frac{dP}{dT} \qquad /6/$$

$$v_{xr} = \sqrt{\frac{b}{\rho}\frac{dP}{dT} - v_{xg}^2}$$

one can get the shear stress velocity on the rough wall.

The dimensionless velocity ratio $\frac{V}{V_{xr}}$ can be plotted against logarithm of the distance from the smooth wall

$$\frac{v}{v_{xr}} = A + 5.75 \log \frac{y}{k} \qquad /7/$$

Equation /7/ represents the universal velocity distribution law for a rough wall. The intercept A of the straight line on the dimensionless velocity axis for a turbulent flow, as shown by NIKURADSE /1931/ depends only on the type of the roughness of the wall.

NIKURADSE has determined the constant A for various relative roughnesses on a particular sand and has established that for similar surface geometries with sands of different particle parameter A has a constant value

$$A_s = 8.48$$

Such tests have been conducted on saw-tooth joint surfaces. For joint surfaces with similar form but different heights of the asperities one single value of A was thereby obtained.

In further tests the constant A was determined for asperities of different inclinations in joint models with saw-tooth joint surfaces. The results as a function of the inclination of the asperities i are shown in Fig. 4.

Some tests were then conducted on plaster casts of a sandstone and a granite joint surface. On the basis of these tests and the tests on

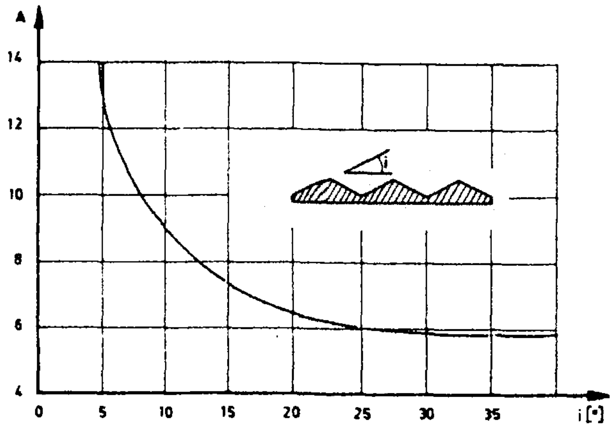

Fig. 4 : Relation between the roughness constant A and inclination i for symmetrical asperties.

saw-tooth joint models dilatation angles of 6° and 7° were obtained for sandstone and the granite joint surface respectively. The angles are slightly lower than the angles obtained by RENGERS /1971/ and SCHNEIDER /1975/ in direct shear tests on joint surfaces of these rocks. RENGERS got an angle of 11° for somewhat rougher tension joints in this granite and SCHNEIDER an angle of 10.5° for the sandstone joint.

Considering the size of samples used in the different tests /RENGERS and SCHNEIDER used samples with a joint surface area of only 500 cm^2 whereas in this investigation the samples had a surface area of 10 000 cm^2/ the results of 6° and 7° seem realistic. Further, the average roughness determined statistically for the surface, was equivalent to inclinations of 5° and 6° for the sandstone and the granite joint respectively.

Summarising it can be stated that in future one cannot dispense with the large scale in-situ tests for the determination of friction angles on rock joints, but that the simple and cheap method described above provides a means for eliminating uncertainties in choosing a representative friction value by performing a large number of tests. Further by combining this method with the conventional friction tests, one can keep the size of the samples to be tested for determining the residual friction relatively small.

References

NIKURADSE J. /1931/: Strömungswiderstand in rauhen Rohren. Z.angew. Math. Mech., 11, 409-411.

PATTON F.D. /1966/: Multiple modes of shear failure in rock. Proc. 1 Congr. Int. Soc. Rock Mech., Lisabon, Vol. 1, 509-513.

RENGERS N. /1971/: Unebenheit und Reibungswiderstand von Gesteinstrennflächen. Veröff. Inst. Boden- u. Felsmechanik, H. 47, Karlsruhe, 129 p.

SCHLICHTING H. /1936/: Experimentelle Untersuchungen zum Rauhigkeitsproblem. Ingenieur-Archiv, VII, 1-34.

SCHNEIDER H.J. /1975/: Reibungs- und Verformungsverhalten von Trennflächen in Fels. Diss. Universität Karlsruhe, 166 p.