| Places of sampling | Depth of sampling in metres | Number of shear zones | Thickness of shear zone, mm | Orientation index /C/, % |
|---|---|---|---|---|
| 1. Valley of the Obla river | 4.60 | 10 | 0.25 | 75 |
| 2. Quarry in the town of Kolpino | 2.10-5.10 | 2-4 | 0.1 | 58 |
| 3. Valley of the Msta river, v. Priluki | 0.4-0.8 | 10 | 1.25 | 82 |
| 4. Valley of the Msta river, v. Plashkino | 3.0-4.3 | 15-20 | 1.25 | 88 |
| 5. Quarry near Novgorod | 2.5: 3.7 | 1-3 | 0.25 | 68 |

Table 1: The orientation indices in the clayey sliding zones

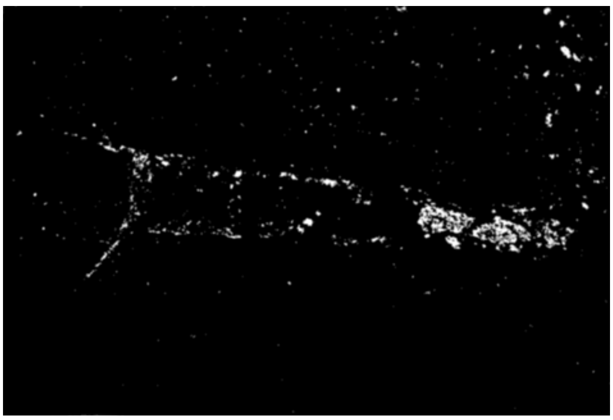

**Fig. 2 : Microphoto of a varved clay section – development of microfissures along the shear zone. Crossed nicols. Enlargement 270.**

Microdisplacements can be explained as a manifestation of the Recent tectonic movements in these regions, which is in keeping with investigations carried out by Dmitriev and Riss /Dmitriev, Mozhaev and Rukoyatkin, 1965; Riss, Mozhaev and Golovin, 1964/. In 1964 these authors distinguished recent tectonic structures of the third order on the Russian Platform. The sampling localities were primarily on the slopes of the structures, where the rocks having been involved in the general upheaval apparently experienced the greatest tension: this results in the development of micro-deformations and "shift textures".

In this manner, the investigations have demonstrated that studies of the weakened zones may offer a proper insight into the mechanism of the slide displacements in clayey rocks and can serve as a basis for the prediction of slope stability.

### References

ANOSOVA L.A. - KOROBANOVA I.G. - KOPILEVA A.K. /1976/: Regularities of the landslide accumulations properties development. Nauka.

DMITRIEV V.D. - MOZHAEV B.N. - RUKOYATKIN A.A. /1965/: Revealing of Holocene tectonic movements in the near - Neva - near-Ilmen depression by the lake-shore-glacial terraces deformations. Earth crust modern movements, 2, Tartu.

RISS Yu.A. - MOZHAEV B.I. - GOLOVIN I.V. /1964/: The study of structures of the north-western area of the Russian Platform in relation to the underground gas-repository search.

BULLETIN of the International Association of ENGINEERING GEOLOGY de l'Association Internationale de GEOLOGIE DE L'INGENIEUR N°16, 235–239 ,KREFELD 1977

# THE TIME DEPENDENCE OF FRICTION OF ROCK JOINTS

# L'INFLUENCE DU TEMPS SUR LE FROTTEMENT D'UNE DIACLASE DE ROCHE

**SCHNEIDER** H., Institute for Soil Mechanics and Rock Mechanics, University of Karlsruhe, Karlsruhe, F.R. Germany*

Summary:

For the determination of the time dependent friction behaviour on rock joints laboratory tests (in principle direct shear test) are conducted. "Opalinuston" as a weak rock was used as test material. The tests are carried out under controlled strain conditions at different shear rates. The results show that the friction resistance depends on shear rate and relative movements. For constant relative movements and a constant normal stress a logarithmic relation between friction resistance and shear rate results. By determining the dependence of the viscoplastic friction on relative movement a creep curve can be deduced describing the friction behaviour of a joint in the examined time range.

* Institut für Bodenmechanik und Felsmechanik, Universität Karlsruhe, Richard-Willstätter-Allee, D-7500 Karlsruhe

Résumé:

L'influence du temps sur le frottement d'une diaclase de roche a été déterminée dans des éssais de frottement (en principe des éssais de cisaillement directs). Comme materiau d'essai on a utilisé une roche tendre du nom de "Opalinuston". Les éssais ont été effectués dans des conditions "strain controlled", avec différentes vitesses relatives de cisaillement. Les résultats montrent l'influence de la vitesse et de la grandeur de la déformation sur la résistance au frottement. Il existe une relation logarithmique entre la résistance au frottement et la vitesse de déformation pour un même mouvement relatif et une contrainte normale constante. A partir de la relation entre la résistance au frottement et la déformation, on peut déterminer le comportement au fluage de la diaclase.

## 1. Introduction

To judge the stability of slopes in which creep movement takes place an extensive programme of in situ measurements at the surface and in boreholes is necessary to obtain a rough idea of motion development with time. For the calculation of slope stability and the estimation of slope movements in time periods relevant to engineering work, knowledge about the time dependent material behaviour is absolutely essential. Investigations into the rheological behaviour of clay soils have been conducted successfully /Leinenkugel, 1976/; they lack however for rock masses. Slope movements in rock show a special characteristic due to presence of joints. This creep movement depends mainly on the joint parameters, especially the time dependent friction behaviour of rock joints. Results of tests investigating the time dependent friction behaviour along single joints are the subject of this study.

## 2. Methods of investigation

The time dependent material behaviour is generally determined in creep tests, i.e. the deformation in time under constant load is measured. This testing technique demands a high accuracy and constancy of testing conditions regarding temperature, humidity, stability of measuring devices over long time periods, freedom from vibration and long testing times. Such tests can be carried out on clay soils within reasonable time, because of the relatively low viscosity of this material. Due to their higher viscosity testing times necessary for rocks would be in the order of years, so that such studies can hardly be afforded. A further difficulty is the scarce knowledge of the viscous properties of rock joints which makes it difficult to choose relation between normal and shear load yielding measurable deformations without leading to collapse.

These time consuming creep tests are better replaced by strain controlled shear tests at different deformation rates. They demand a minimum of time and justifiable expenditure for the experimental set up.

The friction resistance of rock joints is determined in the direct shear test. The examined test samples are provided with a pre-existing joint.

The tests have been conducted with a servo controlled shear apparatus /Schneider, 1976/. The servo control system allows a constant shear rate and constant normal load with unhindered dilatation of the joint. The shear rate varies from $10^{-3}$ mm/min to 4 x $10^2$ mm/min, which gives a spectrum of speed of 4 x $10^5$ mm/min. The speed of the shear apparatus is limited by the regulation accuracy of the electric system and the accuracy of the mechanical bearings at low speeds and by the pumping capacity of the hydraulic aggregate as well as the rate of flow of the servo valve at high speeds. Creep tests cannot satisfactorily be conducted in this shear apparatus, because of the insufficient regulation accuracy of the servo system over longer periods of time.

## 3. Test material

In the tests a weak clay rock /Opalinuston/ from the Jurassic deposits /Alenium/ from Heiningen near Göppingen /Baden-Württemberg/ is investigated. The samples are extracted by boring large rock cores with a diameter of 600 mm /Wichter et al., 1976/. All rock cores come from the same locality and the same stratum. The joints of the shear samples are produced by sawing parallel to bedding. The saw cut gives the joint i.e. the shear plane a flat and smooth appearance. The "Opalinuston" shale has an average uniaxial strength of 3 MN/m$^2$ with a water content of 7 %. The size of the shear area amounts to 500 cm$^2$.

The lower sample is larger than the upper one to enable a constant contact area during the test. The prepared sample is fixed in shear boxes with epoxy resin.

## 4. Testing procedure

The friction resistance is determined for a particular sample at a definite normal load, i.e. normal stress while the shear rate is varied in seven cycles from 1, 10, 100, 200, 1, 0.1 and 0.01 mm/min. The relative movement of each cycle amounts to 10 mm. After each cycle the sample is reloaded. The shear movement starts after a period of 10 mm of preloading. The time for a single cycle requires ranges from 2 sec to 16 h. The load increments vary from 0.3 - 2.0 MN/m$^2$.

## 5. Test results

The diagrams of tangential stress versus relative movement show the same characteristics for all tests. Up to a relative movement of 0.25-1 mm the friction resistance increases nearly linearly, from there on it tends towards its maximum value in a non-linear fashion /Fig. 1/.

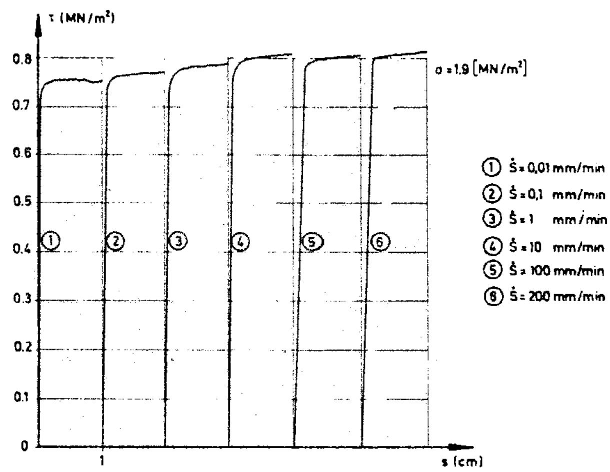


Fig. 1 : Shear stress $\tau$-relative movement (s) diagram of friction tests with constant normal stress $\sigma$ = 1.9 (MN/m$^2$) and different shear rate Ṡ.

The curves can therefore be divided in two parts, a linear elastic and a visco-plastic part. According to Goodman et al. /1972/ the linear elastic part represents the shear stiffness. When the sample is unloaded while still in this linear elastic range, the shear deformations are reversible. If the sample is also unloaded in the normal direction, this deformation, which is due to the shear stiffness does not occur.

In the tests with the same normal stress the friction resistance is larger at higher shear rates. Therefore the friction resistance depends on normal stress, relative movement and shear rate.

$$\tau = f\ (\sigma, S, \dot{S}) \qquad /1/$$

In comparing the friction resistance at a distinct normal stress and a distinct relative movement for example at S = 7 mm for various shear rates, a logarithmic relation between the friction resistance and shear rate can be derived /Fig. 2/,

$$\tau = \tau_0 + K \ln \dot{S} ; \dot{S}_1 \qquad /2/$$

where $\tau_0$ is the friction resistance at the shear speed of $\dot{S} = 1$ mm/min and the factor K the gradient of the logarithmic $\tau$ - $\dot{S}$ relation. The shear speed $\dot{S}$ is normalized to $\dot{S}_1 = 1$ mm/min, so that the factor K gets the dimension of a stress. $\tau_0$ and K grow with increasing normal stress /Fig. 2/.

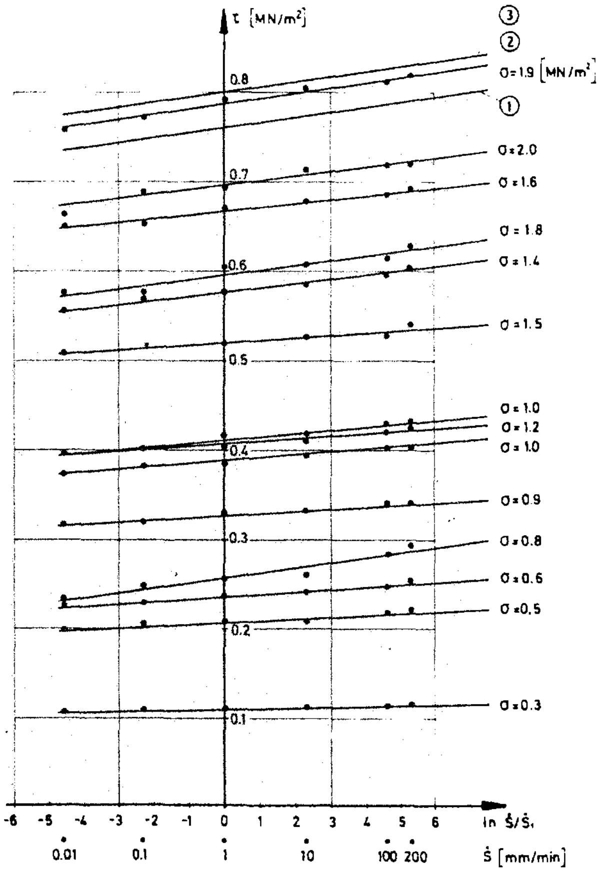


Fig. 2 : Shear stress ($\tau$)-normalized shear speed ($\dot{S}/\dot{S}_1$) diagram for various levels of normal stress $\sigma$ at a relative movement of S= = 7 mm

① $\tau$-$\dot{S}/\dot{S}_1$ relation for a relative movement of S = 0.25 – 1 (mm)

② $\tau$-$\dot{S}/\dot{S}_1$ relation for a relative movement of S = 7 (mm)

③ $\tau$-$\dot{S}/\dot{S}_1$ relation for a relative movement of S = 10 (mm)

and a normal stress of $\sigma$ = 1.9 (MN/m²)

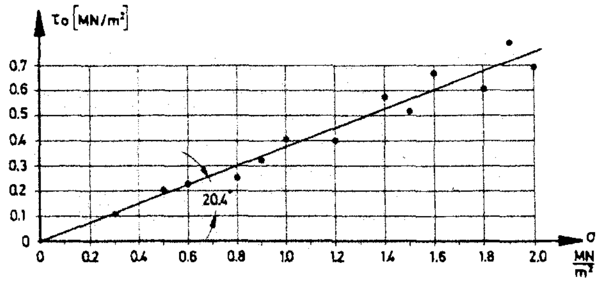


Fig. 3 : K-$\sigma$diagram
the factor K is determined for the friction resistance at a relative movement of S = 0'25 – 1 mm ($\Delta$), S = 7 mm (+) and S = 10 mm (0)

The relation between the tangential stress $\tau_0$ and the normal stress $\sigma$ follows the Coulomb-Navier law /Fig. 3/.

$$\tau_0 = \sigma \tan \rho_0 \qquad /3/$$

/$\rho_0$ is the friction angle determined at the shear speed $\dot{S}_1 = 1$ mm/min and a distinct relative movement/.

The factor K is linearly related to the normal stress according to the function /Fig. 4/.

$$K = m\,\sigma \qquad /4/$$

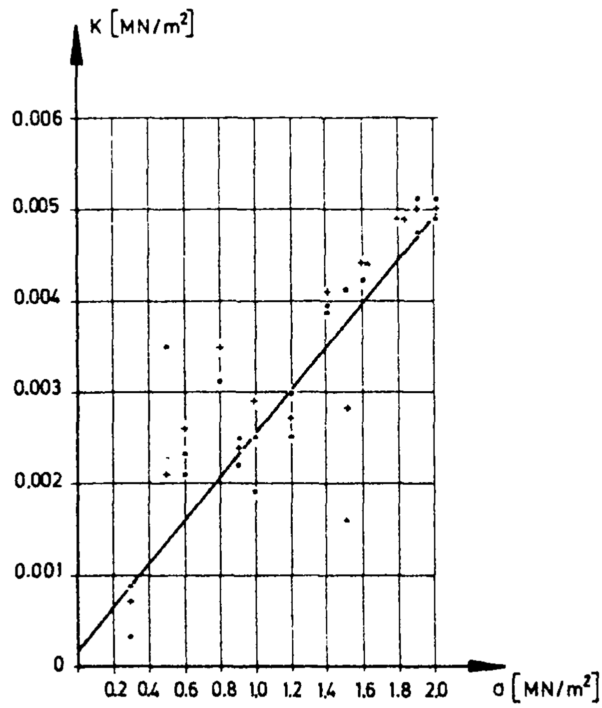


Fig. 4 : $\tau$-$\sigma$-diagram determined for friction values at a relative movement of S = 7 mm and a shear speed of $\dot{S}_1$ = = 1 mm/min

Inserting equations /3/ and /4/ in equation /2/ the following function is arrived at:

$$\tau = \sigma \tan \rho_0 + m\,\sigma \ln \dot{S} / \dot{S}_1 \qquad /5/$$

/This relation is valid only for the distinct relative movement S = 7 mm/.

In an insert step it has to be examined whether relation /5/ also applies to other relative movements. To check this the minimum and maximum values within the visco-plastic range have been considered. /The minimum being the $\tau$-value at the linear elastic-visco-plastic transition at S = 0.25-1 mm and the maximum being the value at S = 10 mm/.

It is found that for both friction resistance values relation /5/ is also valid. The factors K determined for equal normal stress but different relative movements are nearly identical /Tab. 1/: this implies also an identical factor m /Tab. 2/.

| σ | K [MN/m²] | | |
|---|---|---|---|
| MN/m² | $S_1$ = 0.25 - 1mm | $S_2$ = 7 mm | $S_3$ = 10 mm |
| 0.3 | 0.0009 | 0.0007 | 0.0003 |
| 0.5 | 0.0035 | 0.0021 | 0.0032 |
| 0.6 | 0.0023 | 0.0026 | 0.0021 |
| 0.8 | 0.0031 | 0.0035 | 0.0031 |
| 0.9 | 0.0024 | 0.0023 | 0.0022 |
| 1.0 | 0.0025 | 0.0029 | 0.0019 |
| 1.2 | 0.0030 | 0.0027 | 0.0029 |
| 1.4 | 0.0038 | 0.0041 | 0.0039 |
| 1.5 | (0.0016) | (0.0028) | 0.0041 |
| 1.6 | 0.0044 | 0.0044 | 0.0042 |
| 1.8 | (0.0071) | 0.0056 | 0.0044 |
| 1.9 | 0.0049 | 0.0050 | 0.0051 |
| 2.0 | 0.0060 | 0.0054 | 0.0054 |

Table 1 : factor K in dependence on normal stress and relative movement.

| | $S_1$ = 0.25 - 1mm | $S_2$ = 7mm | $S_3$ = 10 mm |
|---|---|---|---|
| m | 0.002282 | 0.00242 | 0.002279 |

Table 2 : Factor M determined from factor K at different relative movements.

This means that the visco-plastic parts of $\tau$-S curves have to be parallel to each other. The transition point from linear-elastic to visco-plastic friction however depends on shear rate. For low rates the transition point is reached after a shorter relative movement than for higher shear speeds /compare Fig. 1/.

No physical explanation exists for this phenomenon, which is of no consequence for the further investigation, because only the viscoplastic part of the friction diagram is taken into consideration.

As mentioned above, the friction resistance $\tau$ in the friction diagram can be divided in a linear elastic part $\tau^*$ and a visco-plastic part $\tau'$

$$\tau = \tau^* + \tau' \qquad /6/$$

This is also valid for the relative movement S with a linear elastic part S* and a viscoplastic part S´

$$S = S^* + S' \qquad /7/$$

For the viscoplastic part the dependence of shear stress on relative movement can be expressed as

$$\tau' = \frac{1}{b} \ln\left(\frac{S'}{a} + 1\right) \qquad /8/$$

Between observed and calculated diagrams a close correlation exists. Because the factor K for equal normal stress and distinct relative movements is constant, the function /8/ is also valid for $\tau'_0$

$$\tau'_0 = \frac{1}{b} \ln\left(\frac{S'}{a} + 1\right) \qquad /9/$$

The friction resistance $\tau_0$ at a shear speed of $\dot{S}$ = 1 mm/min is given as

$$\tau_0 = \tau^*_0 + \tau'_0 \qquad /10/$$

Inserting of equations /6/ and /10/ in equation /2/, a speed dependent friction law taking into account the effect of relative movement can be derived:

$$\tau = \tau^*_0 + \frac{1}{b} \ln\left(\frac{\dot{S}}{a} + 1\right) + K \ln \dot{S}/\dot{S}_1 \qquad /11/$$

That means

$$\dot{S} = \dot{S}_1 e^{\left(\frac{\tau - \tau^*_0}{K}\right)} e^{\left(-\frac{1}{bK} \ln\left(\frac{S'}{a} + 1\right)\right)} \qquad /12/$$

By integrating the shear speed over time

$$S' = \int \dot{S}\, dt$$

the equation

$$\frac{a}{\frac{1}{bK} + 1} \left(\frac{S'}{a} + 1\right)^{\left(\frac{1}{bK} + 1\right)} = \dot{S}_1 (t - t_0)\, e^{\left(\frac{\tau - \tau^*_0}{K}\right)} \qquad /13/$$

results, representing a relation between relative movement and time, from which creep curves can be determined. The creep behaviour of a friction block on a sliding plane can be regarded as a simple static case with constant tangential force causing the movement and a constant normal force. The necessary creep curve can be determined for constant shear stress and the distinct normal stress from equation /13/ /Fig. 5/.

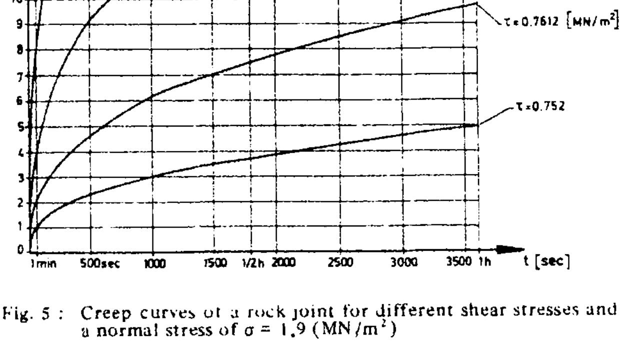


Fig. 5 : Creep curves of a rock joint for different shear stresses and a normal stress of σ = 1.9 (MN/m²)

Thereby the shear stress has to be chosen in such a manner that an extrapolation beyond the examined range is not necessary. Thus reliable creep curves result. From the calculated example /Fig. 5/ it can be seen that already small differences in shear stress suffice to cause a large deviation in the creep behaviour.

**Conclusion**

The friction resistance along joint planes in „Opalinuston" shale is a time dependent property. The time dependent creep behaviour can be determined in strain controlled direct shear tests by deducing from the shear stress-relative movement diagram, at different shear rates, a relative movement-time relation for various constant shear and normal stresses. With this method the expensive and time consuming creep test can be replaced. Small changes in shear stress strongly affect the creep along a joint plane. To obtain measurable sliding movements in creep tests a suitable $\tau$ - $\sigma$ relation has to be selected. This difficulty can be avoided in strain controlled shear tests with different shear rates.

**References**


GOODMAN R.E. - DUBOIS J. /1972/: Duplication of dilatancy in analysis of jointed rocks. Journ. Soil Mech. Found. Eng. Proc. ASCE, SM4, 399 - 422.

LEINENKUGEL H.J. /1976/: Deformations- und Festigkeitsverhalten bindiger Erdstoffe. Experimentelle Ergebnisse und ihre physikalische Deutung. Veröffentl. Inst. Bode- und Felsmechanik, Karlsruhe, Heft 66.

SCHNEIDER H.J. /1976/: Influence of machine stiffness and shear rate on the friction behaviour of rock joints. Bulletin IAEG, 13, 109 - 112.

WICHTER L. - GUDEHUS G. /1976/: Ein Verfahren zur Entnahme und Prüfung von geklüfteten Grossbohrkernen. Proc. 2. Nationale Tagung für Felsmechanik, Aachen, 5 - 11.


BULLETIN of the International Association of ENGINEERING GEOLOGY de l'Association Internationale de GEOLOGIE DE L'INGENIEUR N°16, 239 – 241 ,KREFELD 1977

# THE APPLICATION OF MICROPALEONTOLOGY IN ENGINEERING-GEOLOGICAL RESEARCH OF LANDSLIDES AND SLOPE MOVEMENTS

## L'APPLICATION DE LA MICROPALÉONTOLOGIE A L'INVESTIGATION GÉOTECHNIQUE DES ÉBOULEMENTS ET DES MOUVEMENTS DE TALUS

**SCHUTZNEROVA–HAVELKOVA** V., Technical University, Chair of Geotechniques, Prague, Czechoslovakia*
**WOZNICA** L., Geotest, Brno, Czechoslovakia**

Summary:

The authors call attention to positive results of microbiostratigraphic analysis used in the engineering-geological investigation of large landslides under complicated geological and tectonic-structural conditions. The landslides area is situated at the contact of the Silesian and Subsilesian nappe structures of the outer Carpathian Flysch Belt. An accurate stratigraphic assignment of monotonous Cretaceous and Paleogene incompetent pelitic rocks permits to determine more precisely their tectonic position in the nappes and in the landslide area. The geologic-tectonic predisposition caused the local stability decrease of the valley slopes.

Résumé:

Les auteurs de l'article présentent les résultats d'une analyse microbiostratigraphique, effectuée au cours de la recherche de géologie apliquée dans le domaine des glissements survenus dans des conditions géologiques et tectoniques compliquées. Le lieu de glissement est situé à la frontière de deux nappes, l'une Silésienne, l'autre Subsilésienne, de la zone extérieure des Carpathes de Flysch. Un rangement stratigraphique très précis des sediments monotones de crétacé et paleogène a expliqué leur position tectonique dans les nappes et dans le domaine de glissement. La prédisposition géologique et tectonique a conditionné l'abaissement locale de la stabilité entière de la pente de la vallée.

**1. Introduction**

In studying the slope movements in marine pelitic sediments, micropaleontological /MPA/ investigation has brought good results. Microbiostratigraphic /MBS/ analyses have contributed to the solution of the problems concerning the engineering-geological conditions of slope stability.

In Czechoslovakia, the MPA method was used for a reliable recognition of areas endangered by sliding in marine pelitic sediments of the Cretaceous Basin of Bohemia, in those of the Beskydy Mountains, in the West Carpathian Flysch Belt and in the West Carpathian Neogene basins.

* Sibeliova 43, 162 00 Praha 6 – Střešovice
** Kemprdova 13, 615 00 Brno

**2. Methodology**

Analyses of microfaunal associations permit an accurate stratigraphic assignment of sedimentary series and are the basis of the MBS correlation of strata. Theoretical MPA findings are therefore fairly important in the engineering-geological practice, especially in the study of recent and fossil landslide areas. By means of MPA analyses it could be proved with certainty whether certain sediments are deposited in the original undisturbed sequence or were redeposited by exogenous geological processes. According to microfauna the determinations of the detailed stratigraphy or structural-tectonic units in landslide areas were carried out. In this way it was possible to follow up the horizons liable to sliding, and to determine their areal extent. In some cases such analyses made possible age determinations of slope movements as well as determinations of the course of recent or fossil slide surfaces, and of the landslide depth.