Complex Investigations of Tertiary Fissured Clays

Récherches Complexes d'Argiles Dérangées de Tertiaire

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SYNOPSIS There are some difficulties connected with the stability of slopes in overconsolidated clays. The paper outlines ideas of the formation of fissures owing to regional geological and technical processes. Results of the investigation of strength on slickenside fissures are given. In addition comments on the stability analysis of slopes in such fissured materials are presented.

INTRODUCTION

There are slickenside fissures in overconsolidated, finegrained tertiary layers. They are very important for the stability of slopes. Their effect is based on

(i) a general reduction of shear strength in a material with fissures in comparison with such strength in intact material and

(ii) a special reduction then, when slickenside fissures and failure plane are parallel. Then only a much decreased shear strength on the fissures is effective.

It is often very difficult to obtain extents, trends, dips and character of fissures by boring reports and sempling of drillings solely. There fore it is a necessity to deduce the existence of fissures from the knowledge of the regional geologic situation. Thorough investigations (Molek et al. (1979)$_1$; Förster et al. (1979)$_2$ show mainly three genetically caused categories of slickenside fissures in the GDR

(i) tectonic and glacigenously caused fissures
(ii) irregular small sited fissures and
(iii) technologically caused fissures (due to cutting).

It is possible to derive models of structure connected with the stratigraphic conditions by extensive investigations.
Very important is the value of shear strength along the slickenside fissures and that of fissured material. It reveals, that there is often an ultimate strength highes than the usual residual strength on the slickensided fissures. The general effect of fissures to the strength is shown by Marsland a. o. (1967). It is possible to confirm his investigations.
Some comments are derivable for estimations on stability of slopes in fissured materials.

STRUCTURAL-GEOLOGICAL INVESTIGATIONS OF FISSURED LAYERS

Fissures caused by endogenous-tectonic factors

Structural-geological investigations reveal that the formation of fissures is connected with compression, stretching and folding. The former events lead to passive or active states of failure. Stress paths are shown in Fig. 1.

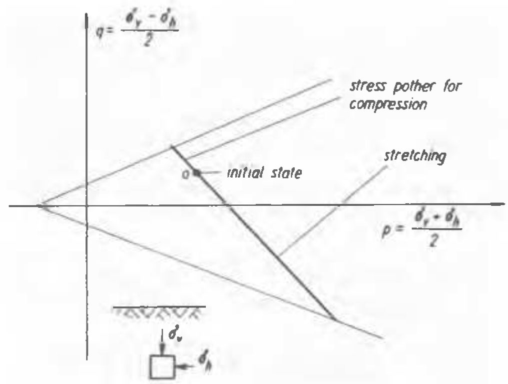

Fig. 1 Stress pathes for compression on stretching

The dips of the failure planes are known to be $\vartheta_a = \pi/4 - \phi'/2$ or $\vartheta_p = \pi/4 + \phi'/2$.

a) An example of the formation of slickenside fissures on compression.
As a result of to compression upthrust and overthrusting are formed. Fig. 2 shows trend and dip of a fault and of the fissures connected with it. There are two systems. One of them is antithetic, the other is synthetic. The angle of dipping is 30...45°. It corresponds nearly to that of a passive state. All slickenside fissures show a lineation in the direction of dipping. The length of the fissures in the direction of striking is, on an average, 38,0 cm; the maximum length is 100,0 cm. The habitus of macrorelief is plane, that of a microrelief

smooth.

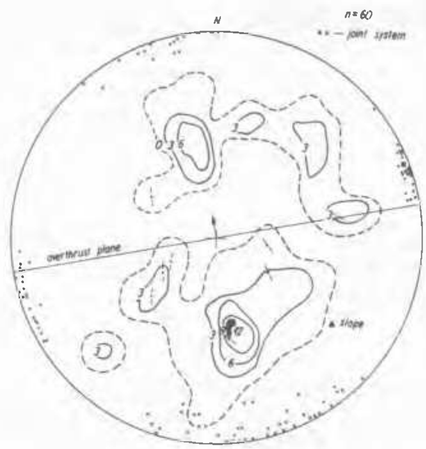

Fig. 2 Contoured stereogram for slickenside fissures near an endogenous tectonic overthrust (compression)

b) An example of forming slickenside fissures on stretching.
The investigations were carried out with a layer with a thickness of (0,4...0,5)m, consisting of clay or silt. The following parameters are characteristic of the material:

particle size: sand = 12,3 %; silt = 41,1 %; clay = 46,6 %

liquid limit W_L = 0,65 plastic limit W_p = 0,25 plasticity index I_p = 0,40 consistency index I_c = 0,98 density of solid particles ϱ_S = 2,60 g/cm^3
content of organic particles I_{om} = 0,12
void ratio e_n = 0,68; activity A = 0,80

Fig. 3 shows the sphere diagramm of the fissures in the region of fault.

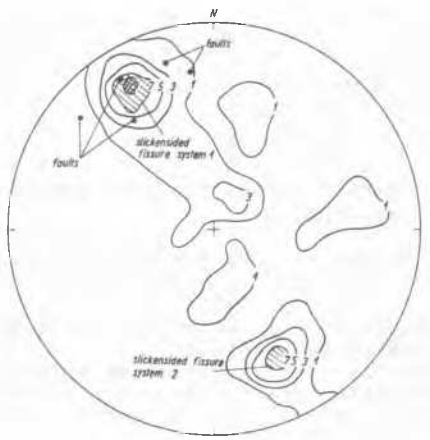

Fig. 3 Contoured stereogram for slickenside fissures near an endogenoue tectonic downthrown fault (stretching)

The marked system of fissures is parallel to the fault. Of secondary importance is a second system with opposite dipping. The mean angle of dipping is 65^o and corresponds to an active failure. Slickenside fissures are particularly numerous near the fault. Their number diminishes with growing distance from the fault. 341 fissures were mapped. Their mean length was (8,0...9,3) cm, their distance to one another was (7,5...10,0) cm. The small distances allow their joining.

Fissures caused by glacigenously factors

During the ice periods the subsoil was stressed due to numerous ice advances. Disturbances, particularly folds were caused. The reasons of load and the effect of shearing together with the resistance of the frozen soils and the rate of the ice advances. Important were physical properties of soils, water content etc.
The formation of fissures in clay in a semi-solid state with a small content of organic substances were investigated. The clay layer was folded. Fig. 4 demonstrates that the fissures reflect the fold structure.

Fig. 4 Contoured stereogram for fissures near a glacigenous folding structure

Slickensids fissures are situated at the flanks of folds. The lineation was obviously parallel to the direction of motion during the process of folding. It shows the direction of thrust during the ice advance. The length of the fissures was (16,4...137) cm; the maximum length was 51,0 m. The distance between the fissures was approximately 25,0 cm. The habitus of fissures is similiar to that of the forms already described.

Fissures irregularly arranged

We can often find structures, in which very small fissures are irregularly distributed in the fine-grained material. It is possible to characterize this as quasi-homogenous. Such formations are obvious in the so-called "Flaschenton" of Lusatia. It is characterized by the following parameters grain size: sand 3 %; silt 48 %, clay 49 %
content of organic materials I_{om} = 0,29
Atterberg limits W_L = 0,64, W_p = 0,26, I_p= 0,38
index of consistency I_c = 1,105
densities ϱ_S = 2,64 g/cm^3, ϱ_n = 1,96 g/cm^3
Further investigations reveal a large over-consolidation ratio. Fig. 5 shows an example

of results of measurements.

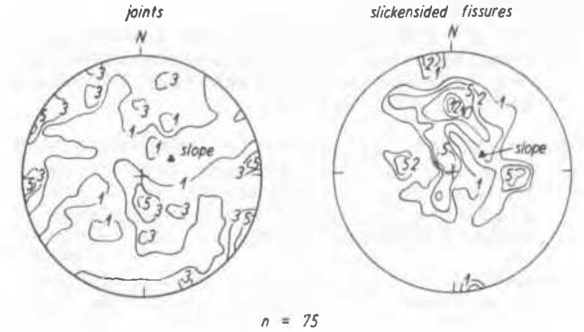

Fig. 5 Irregular small joints and fissures in the so called "Flaschenton"

Both the planes of joints and the fissure planes are irregular. The fissure surfaces have a shape from plane to curved. Mean length was (12,0...30,0)cm.
It is impossible to explain such formations due to tectonic events. They were obviously caused by internal states of stress (swelling, shrinking, freezing and thawing).

Fissures caused by technologically factors

At cuts in the already mentioned "Flaschenton" interfaces are noticed which are parallel to the bedding plane and particularly situated in the lower parts of the slope: They are very long and only a little dipped. They clearly show a lineation, which demonstrates displacement of the slope along there fissure planes. An example is shown in Fig. 6. The dip angle is (1...6)°. In this case the height of the slope was 24,0 m; the thickness of the clay layer was 13,0 m. The technological process of cutting is clearly the reason of such a formation.

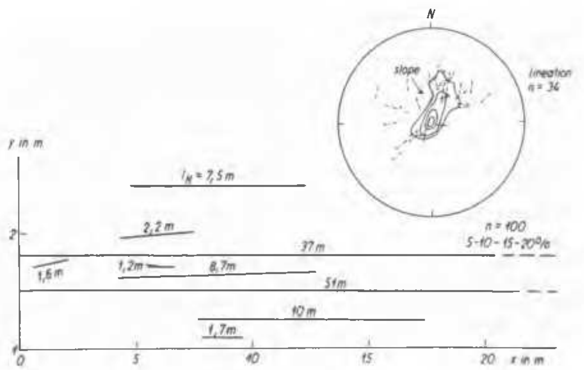

Fig. 6 Bedding plane parallel joints

Summary of engineering-geological investigations

The results of the research work prove a clear relation between the formation of fissures and regional-geological events in the area of investigation. There fore the knowledge of regional-geological conditions makes possible to obtain clues to the eventuality of the occurrence of fissures, to their strike and dip, to their length and lastly to their importance. It was practicable to lay down typical models of structure dependent on bedding conditions. They allow general conclusions about the importance and influence of possible fissures on the stability of designed slopes.

INVESTIGATIONS OF STRENGTH

In fissured clays are of interest

(i) an integral shear strength; the failure plane passes through intact material and fissures. This kind of strength is of special interest for clay with fissures in an irregular pattern.

(ii) the shear strength along the fissure planes. It is of interest for clays with regular systems of orientated fissures of large areas.

Our topic in this paper is only the second. The investigated fissures result from cutting. Important for the investigations are the type of shear device, the influence of deformation rate and the conditions of drainage.
The investigations were carried out in a special shear box described by Fischer (1971). Its advantage is, that the failure plane may develop along the plane of fissure, but the possible displacement amounts on to only (10...15) mm. When tested a "peak" strength along fissure planes was found. Softening happens after a displacement of (1,0...1,5) mm (Fig.7).

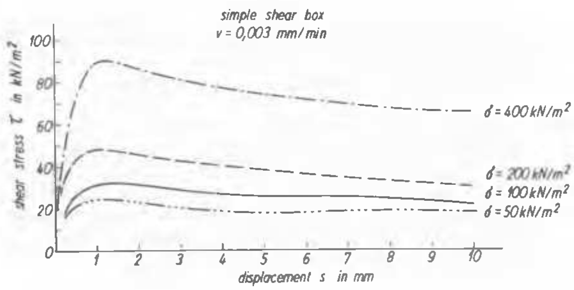

Fig. 7 Shear stress - displacement - diagram for tests along fissure planes

The residual strength was about (0,75...0,90) τ_f. It belonged to the maximum displacement mentioned above. Fig. 8 shows some results of tests of "Flaschenton". The strength along the fissure plane (2,3) is smaller than that of the intact material (1) but higher than the residual strength (4).
When carrying out tests with different displacement rates it becom es evident, that up to a displacement rate of v = 0,03 mm/min the water content at the failure plane rose sufficiently for getting drained condition owing to water suction out of regions adjacent to the failure plane.

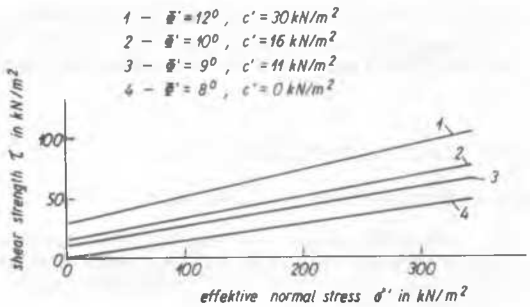

Fig. 8 Shear tests on "Flaschenton"
(1) triaxial test, C/D (pass. compr.)-tests on undisturbed material with irregular pattern of fissures
(2) Shear test in a special box along fissures (peak)
(3) like (2), but after a displacement of 10,0 mm
(4) residual shear strength, determined in a ringshear-apparatus

COMMENTS TO STABILITY ESTIMATIONS IN FISSURED CLAY

For slopes with a short standing time in overconsolidated clays results of our work are the following comments:

(i) Mostly conclusions about properties of regular fissure patterns can be drawn from regional-geological conditions. So it is possible to estimate their influence on the stability of slopes.

(ii) There are only seldom fissures of a large area with a shear strength near to the residual strength of intact material. They may be occur, if overconsolidated materials are redeposited and strengthened in a special manner (rolled out at the place of new deposition).

(iii) It seems to be allowed to calculate with a strength along the fissures which is above the residual strength of the intact material. In most cases there are drained conditions along failure planes.

(iv) For stability calculations a shear strength, taking into account both the strength of the intact material and that along fissure planes is to be chosen.

CONCLUSIONS

In the paper a relation between regional-geological conditions and the rise of fissures is demonstrated. Structural models are formable. Investigation of strength along fissure planes show a strength above the residual strength of intact material. These factors are of particular importance for the stability of slopes.

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