INVESTIGATION OF A SLOPE SLIDE ON THE MOTORWAY M-3*

By

J. FARKAS—L. NAGY

Department of Geotechnique, Technical University, Budapest

Received: February 19, 1981
Presented by Prof. Dr. Árpád KÉZDI

Owing to the topographic conditions in Hungary, buildings, roads, channels, etc. are often to be constructed on hillside slopes where human activity reduces the stability of sloping earth masses.

In certain cases subsurface soil motion or slide on slopes or in cuts intervened soon after, or even during, the construction. Prevention of such soil motions requires a thorough knowledge of the conditions prior to the intervention. From the aspect of geotechnical examinations, the volume of excavations and tests is always insufficient, imposing to rely on assumptions and estimates. Their reliability may much be confirmed by the geological knowledge involving the geohistorical origin of, and the geological influences on, the area in question, as well as observations made during the construction.

The motorway M-3 passes through one of the attractive, hilly regions of Hungary. The involved earthwork is unique in this country by the earth masses transferred, by the height of embankments and by the depth of cuttings.

The considered slope slide took place between sections 38 + 100 and 38 + 400, on the slope of the hillside to the south from the motorway trace. This hillside was also used as borrow area for earthwork construction.

This is a straight reach of the motorway before the village *Kisbag*. In the section 38 + 200, the road deck is at 137.66 m above Baltic Sea level.

The original hillside sloped 16—18 percent to the north-west; the envisaged slope of the borrow pit was 20 to 26 percent. During earth excavation on 13 April 1978, several thousand cubic metres of earth over an area of 200 m × 130 m slid down toward the motorway. Fortunately, the lower part of the slip surface intersected the slope surface at the edge of the parking lane, thus, the pavement structure was not damaged, only the premixed cement stabilization pavement of the parking lane got damaged along 20 m length and 1 metre width. During the excavation of the slid earth masses and the

---

* This paper relies on data and test results in the diploma work conceived under the direction of the senior author at the Department of Geotechnique, Technical University, Budapest.

slope reconstruction, repeated, seemingly continuous motions took place, the slip surface gradually "receded". The layout of the damaged area is depicted in Fig. 1.

Investigation aimed at finding the causes of landslide and the influence of the geology of the region, structure, mineralogical composition and stability of the soil.

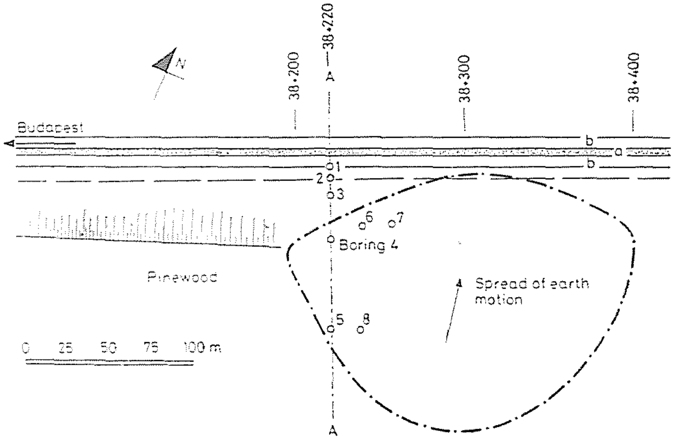

Fig. 1. Layout of the landslide a — central reserve; b — pavement

Description of the region geology

According to the literature on geology, the region considered has developed in the Quaternary. Clays of imminent sliding originated in the Cenozoic. The upper Pannonian layers are surfacing, or nearly, to the north-west from the railway line Gödöllő—Aszód. These are composed, besides of loose light gray or yellowish-brown sand, and hard sandstone shelves (containing 20 to 30 cm thick micacious, calciferous layers), grayish yellow sandy clay, interspersed with streaks of bluish gray clay, some lignitic clay, and marly clay layers of a few cm.

In the slip surface region investigated, also lower Levantine strata are found near the surface. At the bottom of this series of strata there are yellow, gray, brown clays, and above them grayish brown sandy clays (with thin light gray, loose sand lenses). The Levantine strata are here and there overlain by Pleistocene loess, manganese coated gravels and sand lenses, elsewhere by lower Pleistocene, reddish brown, buff, gray, greenish blue lake clays, spotted marshy clays.

The tectonic structure in the region, heterogeneous stratification, strata sloping towards the valley, make the hillside prone to surface movements.

Soil mechanical and mineralogical investigations

Already drillings and soil investigations carried out by the *State Company for Communication, Transport and Traffic Engineering, Planning and Design Services* (UVATERV) for the preliminary design of the motorway had shown that the inclination towards the valley, the variable consistency and mineralogical composition of the soil layers, the presence of periodical interstitial water, loam and sand layers involved the danger of sliding.

After the surface earth masses started to slide (in March and April 1978) UVATERV surveyed the situation and drilled prospect holes in three sections. Data obtained by boring permitted to map the stratification of the hillside sections. A characteristic section (A—A) taken at the location shown in Fig. 1 is represented in Fig. 2 indicating also the slip surface of the receding surface movement subsequent to the terrain correction following the first slope failure.

Explorations offered the following picture of the subsoil.

Below the ground level of the terrain correction subsequent to the first slope failure, yellow, grayish yellow and red clay strata with lens-like deposits of sandy slime and loam were found in thicknesses growing (0—7.3 m) towards the hill. Beneath, all over the area of sliding, yellow, grayish yellow clay 1.0 to 2.5 m thick is found underlain by gray clay, silty fine sand and clay strata.

A typical boring log with soil physical characteristics is shown in Fig. 3. Already in the first site inspection the slip surface was deemed likely to have developed on the interface between the gray fat clay and the overlying yellow clay. Consequently, at the foot of the slide, where the gray fat clay approached the soil surface, large undisturbed soil samples of a cross section of 50 cm × 50 cm were taken from open ditches around the seemingly critical interface. Exploration tranches exhibited a thin light yellow (whitish) plastic clay strip 0.5 to 1.0 cm thick ($w_L = 79$ to 83 percent; $I_p = 45$ to 53 percent, $w = 33$ to

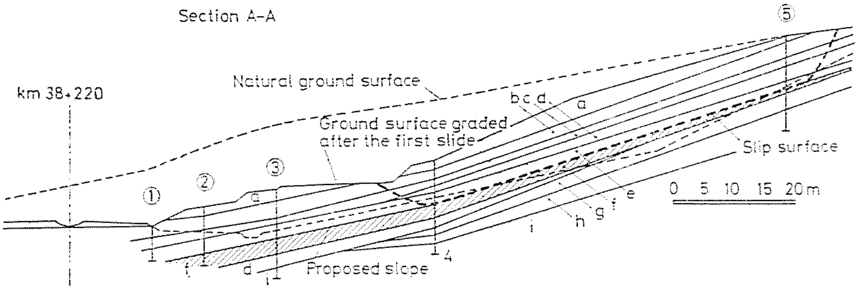

Fig. 2. Section A—A of the area of landslide. a — yellow limy clay; b — yellow lean clay; c — red fat clay with sand veins; d — silty fine sand; e — yellow clay; f — fat gray clay; g — yellow gray fat clay; h — yellow fine sandy clay; i — yellow silt

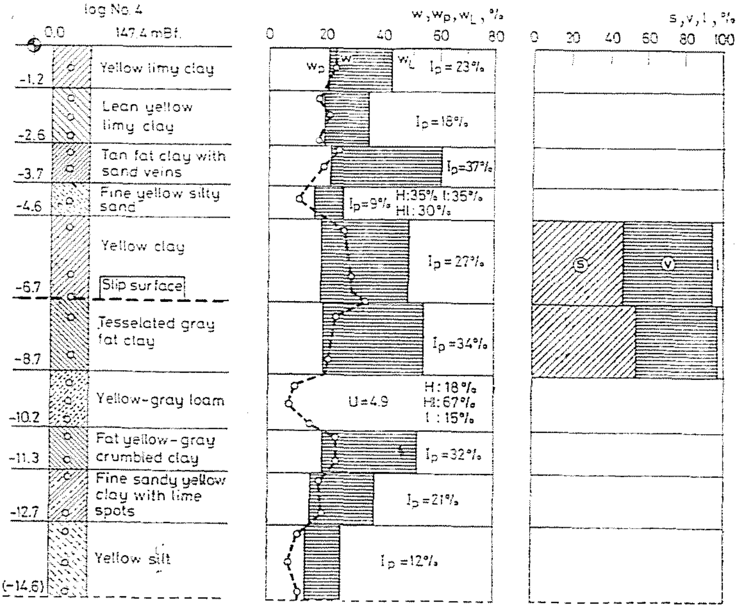

Fig. 3. Section of boring No. 4 and physical characteristics of explored soils

36 percent) separating the layers of gray rich clay and yellow clay, of course unobservable in the course of borings.

Later on, the earth material of the sliding slope was cut down to a depth of 1.0 m below the slip surface starting from the 38 + 350 km section, to the benefit of our investigations. Thus, at the boundary surface of the slope reconstructed and the moving earth mass, a vertical earth wall, of a plane normal to the centre-line of the motorway developed, clearly exhibiting a length of 30 to 40 m of the slip surface on the interface between the yellow clay and the underlying fat gray clay lined all along by the light yellow clay strip 0.5 to 1.0 cm thick. Higher water contents along the interface hint to infiltration and to interstitial water.

The physical characteristics of the typical soils found near the slip surface and those of the soil samples taken from the interface (the light yellow clay) have been compiled in Table 1. The phase composition of the tested soils is represented in the triangle diagram of Fig. 4.

The grading of clays has been tested in a *Sartorius* type sedimentation apparatus. The sedimentation results of the yellow clay above the slip surface and the strip of light yellow clay (in the slip surface) are tabulated in Table 2 as an example.

The specific surface of clays was concluded on from dye adsorption measurements (using methylene blue dye) compiled in Table 3. The specific surface

Table 1

Physical characteristics of soil types

Soil physical characteristic	Symbol (unit)	Yellow clay	Light yellow clay strip (interface)	Fat gray clay
Water content	w %	30—31	33—36	21—24
Liquid limit	W_L %	50—52	79—83	52—72
Plastic limit	W_p %	22—23	30—34	22—23
Plasticity index	I_p %	27—30	45—53	30—49
Shrinkage limit	w_s %	17—18	17—18	15—16
Voids ratio	e	0.85—1.00	0.93—1.18	0.70—0.75
Saturation	S	0.8 —0.9	0.85—1.0	0.82—0.94
Wet bulk density	γ_n kN/m³	18.0—19.6	17.2—19.0	19.5—20.3
Dry bulk density	γ_d kN/m³	14.0—15.0	12.9—14.6	16.0—16.5
Solids percentage	s %	50—54	43—52	57—59
Water percentage	v %	42—46	43—50	35—38
Air percentage	l %	2—7	0—8	4—8

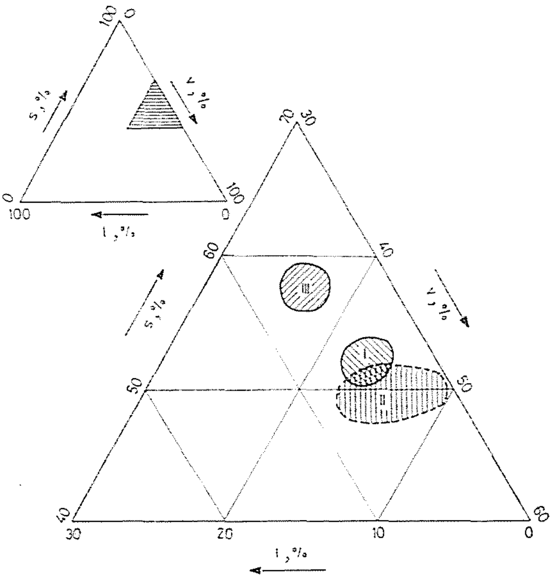

Fig. 4. Phase compositions of soils around the slip surface

of the yellow clay is some 40 percent of that of the fat gray clay and of the interface soil samples.

The results obtained for the liquid limit and plasticity indices of clays are in close agreement with those of a clay fraction. With increasing specific surface, the plasticity index and the liquid limit of the clay grow increasing.

The shear strength parameters of soil samples taken from open ditches were determined partly in triaxial compression tests, and partly in direct shear tests. Consolidated rapid tests were made both on samples of natural water content and on soaked ones. For interface samples subject to direct shear test the shear plane was adjusted to be in the 0.5 to 1.0 cm thick strip of the light yellow plastic clay.

Table 2

Clay fraction grading

Grain size d mm	Yellow clay %	Light yellow fat clay strip (interface) %
0.0020	14.0	30.0
0.0015	5.6	19.5
0.0010	2.0	13.2
0.0008	4.0	10.4
0.0007	0	0.4
0.0006	0	7.0
0.0005	0	4.5
0.0004	0	4.0
0.0002	0	0.7

Table 3

Specific surface of soils surrounding the slip surface

Type of soil	Specific surface m^2/g
Yellow clay	29.5
Light yellow clay strip I (interface)	72.2
Light yellow clay strip II (interface)	77.9
Fat gray clay	72.3

The shear strength parameters of the soil below and above the slip surface and of the interface samples are presented in Fig. 5. It is interesting to see the relatively low value of the internal friction angle of interface samples contain-

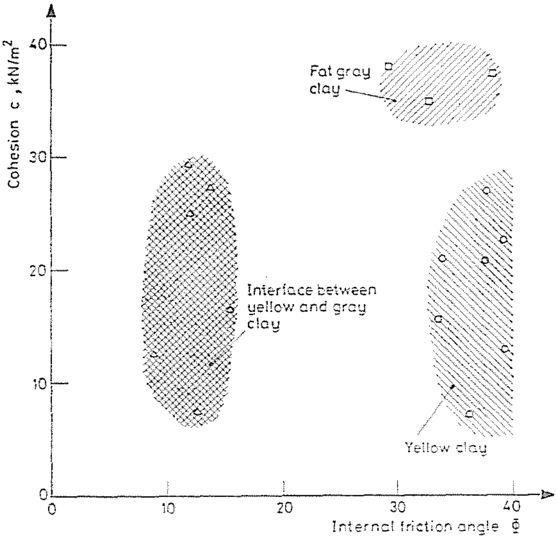

Fig. 5. Shear strength parameter ranges

ing also the slip surface. The *Coulomb* lines showing the direct shear strength values are seen in Fig. 6.

The influence of the water content on the shear strength of clays has been investigated. The relationship for the case of the yellow clay above the slip surface is represented in Fig. 7 as an example.

Results of consolidated undrained direct shear tests showed the increase in water content to significantly reduce the strength. The value of the friction angle practically was little dependent on the water content, the cohesion, however, the other shear strength parameter, decreased exponentially with increasing water content (Fig. 8).

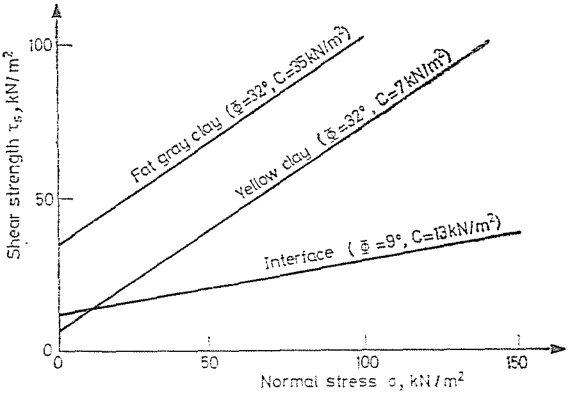

Fig. 6. Coulomb lines of soils near the slip surface

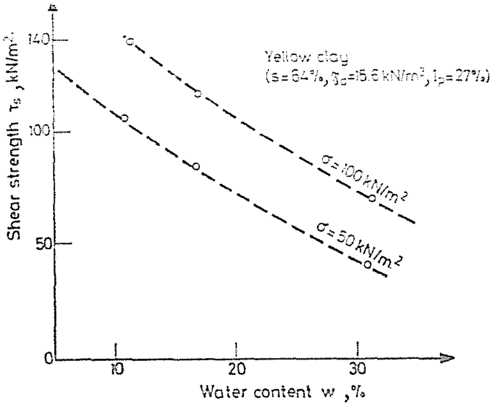

Fig. 7. Shear strength vs. water content

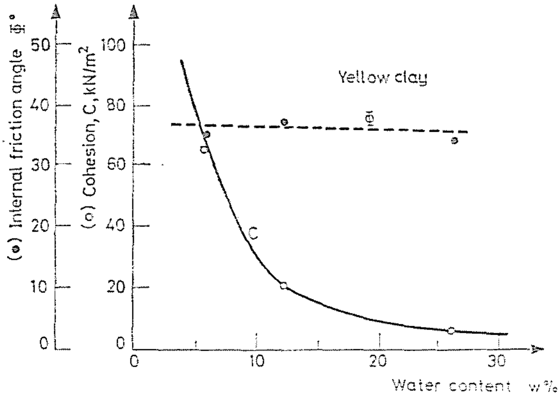

Fig. 8. Shear strength parameters vs. water content

This fact also is a hint that seasonal waters reduce the shear strength. (Of course, it would be premature to draw a general conclusion on the interdependence between the shear strength parameters and water content from the obtained test results.) In this area a continuous water table was found 6 to 13 m deep under the ground surface graded after the first slide.

The mineralogical composition of the soil samples taken near the slope failure was determined by thermoanalysis. The thermoanalytic tests were made on the *Paulik—Erdélyi derivatograph* of the Department of Mineralogy and Geology of the Technical University, Budapest, with the cooperation of senior assistant *Dr. G. Bidló.* The test results are listed in Table 4. It was interesting to see the 50 to 60 percent clay mineral content of the fat gray clay under the slip surface and of the overlying thin strip of light yellow plastic clay, as well as the $CaCO_3$ content (44 to 78 percent) of the yellow clay (at

Table 4

Mineralogical composition of typical soils

Type of soil	Organic matter %	Clay mineral %	$CaCO_3$	Quartz, feldspar %
Red clay	1.1	17.1	1	73
Rockflour	0.3	1.2	16	59
Yellow clay marl	0.5	20	78	0
Yellow clay	0.3	24	44	30
Light yellow fat clay strip I slip surface	1.0	50	7	37
Light yellow fat clay strip II slip surface	1.3	54	22	19
Fat gray clay I	0.5	52—58	1	35
Fat gray clay II	0.5	55—60	6	28

some spots clayey marl) above the slip surface. Illite was the predominating mineral.

The plasticity of the clays is due almost exclusively to the interaction between water and the clay fraction. For a given mineralogical composition of the clay fraction, the plasticity index is proportional to the clay content; but the coefficient of proportionality much depends on the mineralogical composition. The relationship between the plasticity index and the clay mineral content for soils in the slope failure region found by the authors has been plotted in Fig. 9.

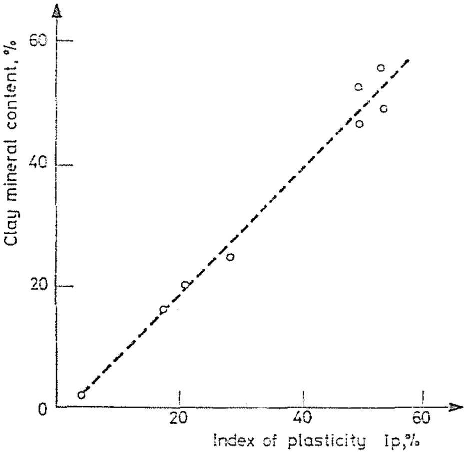

Fig. 9. Plasticity index vs. clay mineral content

Stability analyses

According to field observations, surface phenomena and explorations, the slip surface followed the upper face of the gray fat clay and rose to the surface cambered. Recession of the movement created secondary slip surfaces. The cropping out of the lower part of the slip surface could not definitely be located due to bulging earth masses.

A major peculiarity of slides is to exist in the earth mass of inclined boundary a layer surface along which only a low value of the shear strength resists downward and outward thrusts. The geological preconditions of this type of surface movement prevail in the area considered. According to laboratory test results, the shear strength along the thin strip of light yellow plastic clay at the interface of the yellow clay and fat gray clay was significantly lower than in the surrounding soil strata.

The examined slip surfaces were assumed in conformity with the above described mechanism.

The scheme of balance tests is shown in Fig. 10. The equilibrium condition of the earth mass confined by the combined slip surface and the ground surface was investigated. Dividing the earth mass into three parts, the forces acting on block $\overline{2345}$ were to be determined. The active forces which caused the slide were: the component of load G along the slope and the active earth pressure acting on surface $\overline{45}$. The highest possible value of the forces resisting the movement is the sum of the passive earth pressure acting on surface $\overline{23}$ and of the frictional and cohesion forces to be mobilized on slip surface $\overline{34}$. Accordingly, the safety factor becomes:

$$\nu = \frac{E_p \cos \varepsilon + G \cos \varepsilon \operatorname{tg} \Phi + c \cdot l}{G \sin \varepsilon + E_a \cdot \cos (\delta - \varepsilon)} .$$

The calculations involved a computer program. Since the lower cropping up of the slip surface could not be located because of the bulging earth mass, the weight of the sliding mass of earth was given by lamellation from above

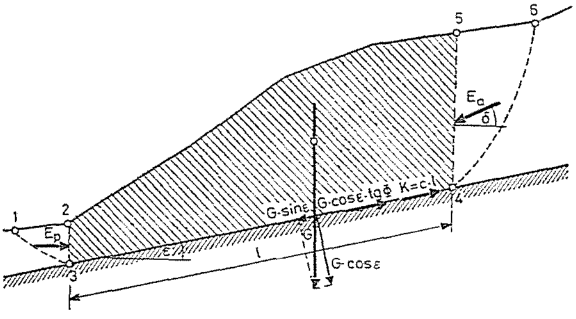

Fig. 10. Scheme of the balance analysis

by cyclic instruction. Thus the value of the safety factor was calculated from the top of the slip surface, by increasing lamella by lamella the mass of moving earth. The slip surface was assigned the worst pair of shear strength parameters obtained from undrained direct shear tests ($\Phi = 9°$, $c = 13$ kN/m^2).

Safety factors $\nu_{\min}$ obtained at sections of 38 + 220 km and 38 + 240 km were 0.39 and 0.83, respectively.

The variation of the safety factor ν upon breaking up the original ground surface was examined at sections of 38 + 220 and 38 + 240 km. The extreme values are found in Table 5. According to the calculations, the safety factor dropped below $\nu = 1$ during the excavation hence the landslide is the consequence of the excavation.

Table 5

Extreme values of the safety factor

Km	38 + 220	38 + 240
Natural soil surface	1.65	1.18
Soil surface graded after the first slip	0.93	0.83

Also the effect of the variation of the shear strengt hparameters is of interest. Assuming the value of the cohesion on the sliding plane to be constant ($c = 13$ kN/m^2), the safety factor varies as a function of the internal friction angle as seen in Fig. 11. Selecting the angle of internal friction as constant ($\Phi = 9°$), the safety factor and the cohesion at the section of 38 + 240 km are related as represented in Fig. 12.

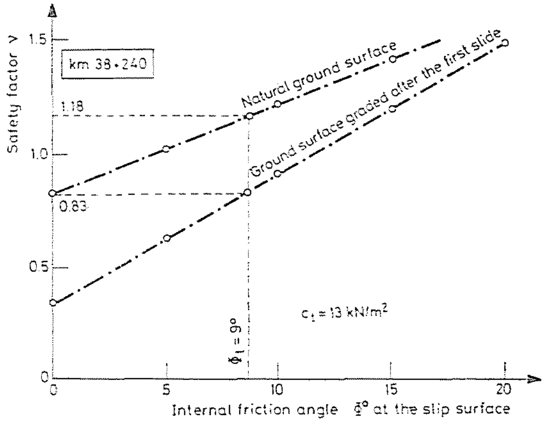

Fig. 11. Safety factor vs. internal friction angle

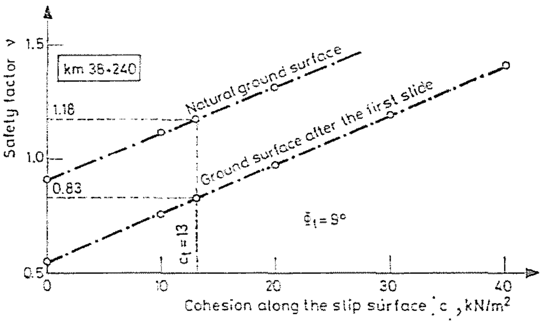

Fig. 12. Safety factor vs. cohesion

At last, the pairs of values (c, Φ) associated with the limit state of equilibrium $\nu = 1$ have been determined to be aligned on the line shown in Fig. 13 together with the range of shear strength parameters on the yellow clay — fat gray clay interface. The straight line $\nu = 1$ intersects the range of available shear strength parameters, pointing to the imperative of movement where and how it occurred.

Let us point out that stability analyses reckoned with shear strength maxima. Often, however, ulterior stability analyses of slid slopes and observed behaviour of natural slopes suggest that the average shear stress along the slip surface at failure is significantly lower than the shear strength calculated from parameters (maxima) obtained in laboratory tests. In such instances the average value of the shear stress referred to the slip surface approximately

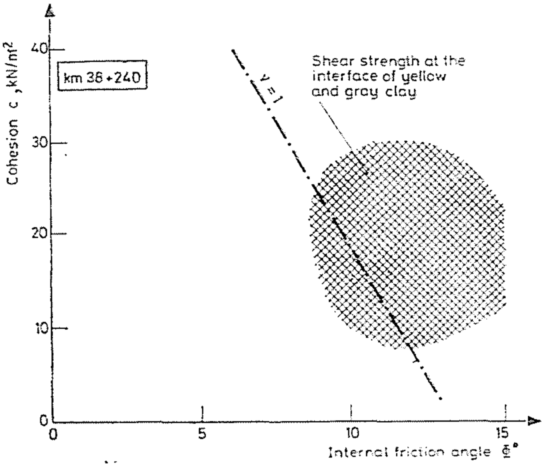

Fig. 13. Correlation between shear strength parameters at ultimate equilibrium indicating the range of actual shear strength parameters at the interface between yellow and gray clays

equals the residual strength; that is, the actual slides may be assumed to be preceded by progressive failure along the slip surface.

This demeanour is typical of geologically preloaded clays, of clay masses interlaced with fine, hidden cracks, of mosaic-like structure, or involving weak planes — interfaces.

The residual shear strength was determined in direct shear tests on samples taken at the site of slope failure from yellow, sandy marl clay. The samples were tested in shear applying different normal stresses, then, following each shear test, the samples were pushed back into their original position and the test was repeated twice or three times. Typical test results are seen in Fig. 14. The clay stiffness caused significant differences between the peak value and the ultimate (residual) value on the curve of shear deformations. Beyond the peak value of the shear strength, shear displacements exceeding the ultimate deformation are only opposed by a minor shear resistance. Namely, on the one hand, the orientation of the flat, scale-like clay particles will change, their former irregular position will be more regular, reducing the shear resistance; on the other hand, variation of the deviator stresses due to the action of shear stresses during the displacement elicits neutral stresses (with axial rotation), further reducing the shear strength.

Thus, at or beyond critical shear displacements, the value of the shear strength will be reduced, reducing the safety factor to below $\nu = 1$. Thereby, the movement will be fast and accelerated and becomes very significant, until

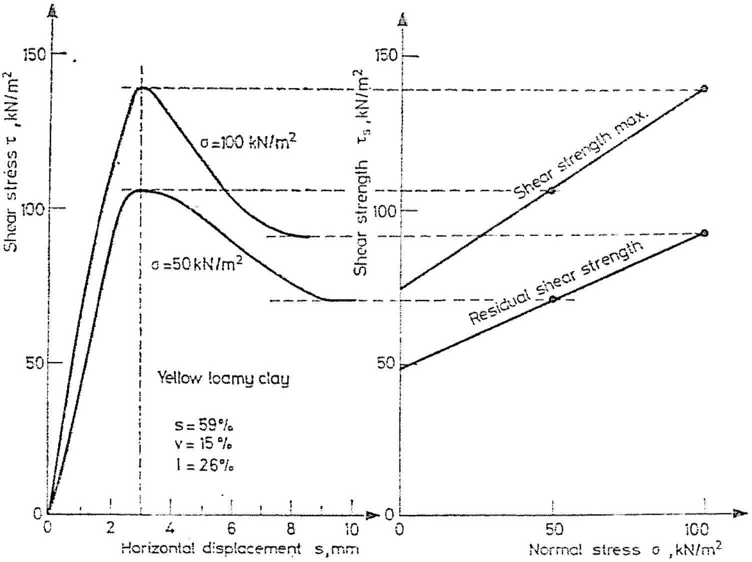

Fig. 14. Characteristic shear displacements of the yellow clay marl; peak and final shear strength values

eventually the earth mass slid down and piled up will gain resistance to stop the movement.

According to the investigations, the subsurface earth movement is due to the coincidence of the following unfavourable effects:

- inclination of the soil strata parallel to the slope;
- disturbance of the hillside (excavation, cut);
- deficient drainage of the temporary slope;
- high water content and insufficient shear strength parameters of the critical interface between soil layers.

Acknowledgements

The authors are deeply indebted to Prof. Dr. *Á. Kézdi*, Head of Department who coordinated the diploma design works at the Department of Geotechnics; to Senior Assistant *Dr. G. Bidló* at the *Department of Mineralogy and Geology* for the careful consultations and valuable help in mineralogical analyses; to Mrs. *Z. Vizi*, civil eng., group leader at UVATERV, for having kindly made us available the records of earlier investigations and for the helpful assistance in field investigations and soil sampling.

Summary

In spring 1978, several thousand cubic metres of earth slid down in one cut of the motorway M-3. The geological structure of the region, the heterogeneous stratification of the soil and the inclination of the strata towards the valley made the hillside *a priori* prone to surface movement. The slip surface developed in the thin (0.5—1.0 cm thick) strip of light yellow clay along the interface between a yellow clay layer and an underlying fat gray clay.

The increased interface water content hinted to infiltration and to the presence of interstitial water. Direct shear tests on interface samples showed a very low internal friction angle compared to that of the surrounding soils. The predominant clay mineral in soils intervening in sliding was illite. Stability analyses showed a safety factor $\nu < 1$, making the slide unavoidable.

References

1. Böckh, I. (1973): Geological conditions in the Fót—Gödöllő—Aszód region.* Földtani Közlöny II. Budapest .
2. Grim, R. A. (1952): Clay Mineralogy. London.
3. Hofbauer, R. (1939): Some particulars on the morphology of the middle reach of the Galga Valley.* Doctor Techn. Thesis, Budapest.
4. Horusitzky, F. (1952): Geological investigations in the Galga basin.* Annual Report of the Hungarian National Institute of Geology.
5. Kézdi, Á. (1976): Soil mechanical practice.* Tankönyvkiadó. Budapest.
6. Kézdi, Á. (1977): Soil mechanics.* Part I. Tankönyvkiadó. Budapest.
7. Kézdi, Á.—Farkas, J.—Kabai, I. (1976): Slide on the Pécskődomb in Salgótarján.* Mélyépítéstudományi Szemle. No. 3.
8. Szentes, F. (1941—42): Geological investigations of Aszód and its greater region. Geography of Hungarian Landscapes.*

Senior Assistant József Farkas } H-1521, Budapest
Assistant László Nagy }

---

* In Hungarian