Earth Movement Investigations in a Landslide Area on the Bosporus

Etude d'un Glissement de Terrain au Bosphore

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Summary

The foot of a steep hill on the Bosporus was excavated to provide a terrace for a factory building. The soil forming the slope is a hard fissured clay. One year later, after a rainy season and a snowy winter, earth movements began to take place, and retaining walls and concrete floor were deformed and cracked. In this case it has been possible to estimate the position of the slip surfaces with a sufficient approximation and to represent them by an arc of a circle. Factors of safety have been calculated for different laboratory values of ϕ and c.

Considering that the factor of safety calculated on the basis of actual slide surface and field values of ϕ and c should be equal to unity, an attempt is made to find a means of choosing a satisfactory ϕ and c value from among the different test results carried out under different conditions.

Sommaire

Une tranchée a été creusée à la base du versant d'une colline pour préparer le terrassement d'une usine. Le sol consiste en argile dure et fissurée. Un an après, à la suite d'une saison pluvieuse et d'un hiver neigeux, des mouvements de terre se sont produits, le mur de soutènement et le plancher, en béton ont été déformés et fissurés. Dans le cas actuel il a été possible de déterminer les différentes positions des surfaces de glissement d'une manière assez précise, et de les représenter par des arcs de cercle. Les coefficients de sécurité ont été calculés pour différentes valeurs expérimentales de ϕ et de c.

En considérant que le coefficient de sécurité calculé sur la base de valeurs réelles de surface de glissement de ϕ et de c doit être de 1, les auteurs ont cherché, parmi les résultats d'essais effectués en laboratoire dans des conditions différentes, une valeur satisfaisante de ϕ et de c.

General Description of the Case

A great number of landslides occur in the area shown in Figs. 1 and 2. This area has been mined for clay for more than 50 years. In Fig. 2 a new system of landslide caused by recent excavations at the foot of the hill is marked by *B*. The site of the new brick and tile factory buildings is marked by *C*. This area had been excavated before as shown in an older map of the area, Fig. 3. The average depth of this first excavation at the site was about 20 m (Figs. 4 and 5).

In the summer of 1954 a terrace was excavated for the new machine house at the foot of the steep slope. The former excavations, made about 40 to 50 years ago, were responsible for the steepness of the slope in this place. The general plan and sections of the terrace and the retaining walls are given in Fig. 6; the dates referring to the construction of the retaining walls.

In the spring of 1955 movements in the retaining walls were first noticed, and cracks on the slope between the contours 60 and 70 running parallel to the walls were observed. Towards the end of 1955 cracks widened and multiplied. The forward movement of the walls amounted by that time to 15 to 65 mm. Dangerous cracks in the masonry and excessive distortions in the steel frames and columns forced the owners to dismantle most of the machinery, so that the plant became inoperative.

Reference points and arrangements (such as plumb lines and reference frames) shown in Fig. 6 were installed to observe and measure further movement. As the rates of movement were not decreasing it was decided, as a safety measure, to strengthen the retaining walls by buttresses. According to the measurements made since 1 January 1956 the rate of the wall movement was about 1 mm/day. At that time the slope was covered with snow, and the soil surface south of the upper slide boundary had subsided in some places more than 2 m.

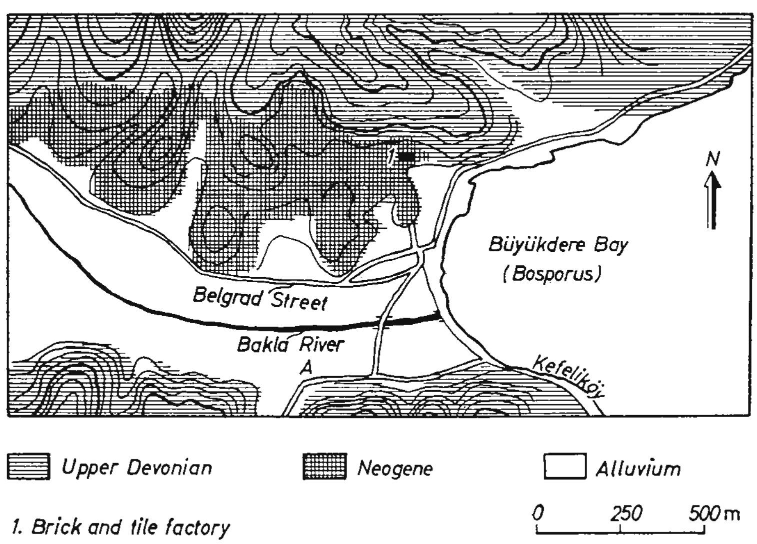

Fig. 1 Location and the geological map of the site
Plan de situation et carte géologique du site

Fig. 2 Landslide area seen from the place marked by *A* in Fig. 1
Zone de glissement vue du point *A* de la Fig. 1

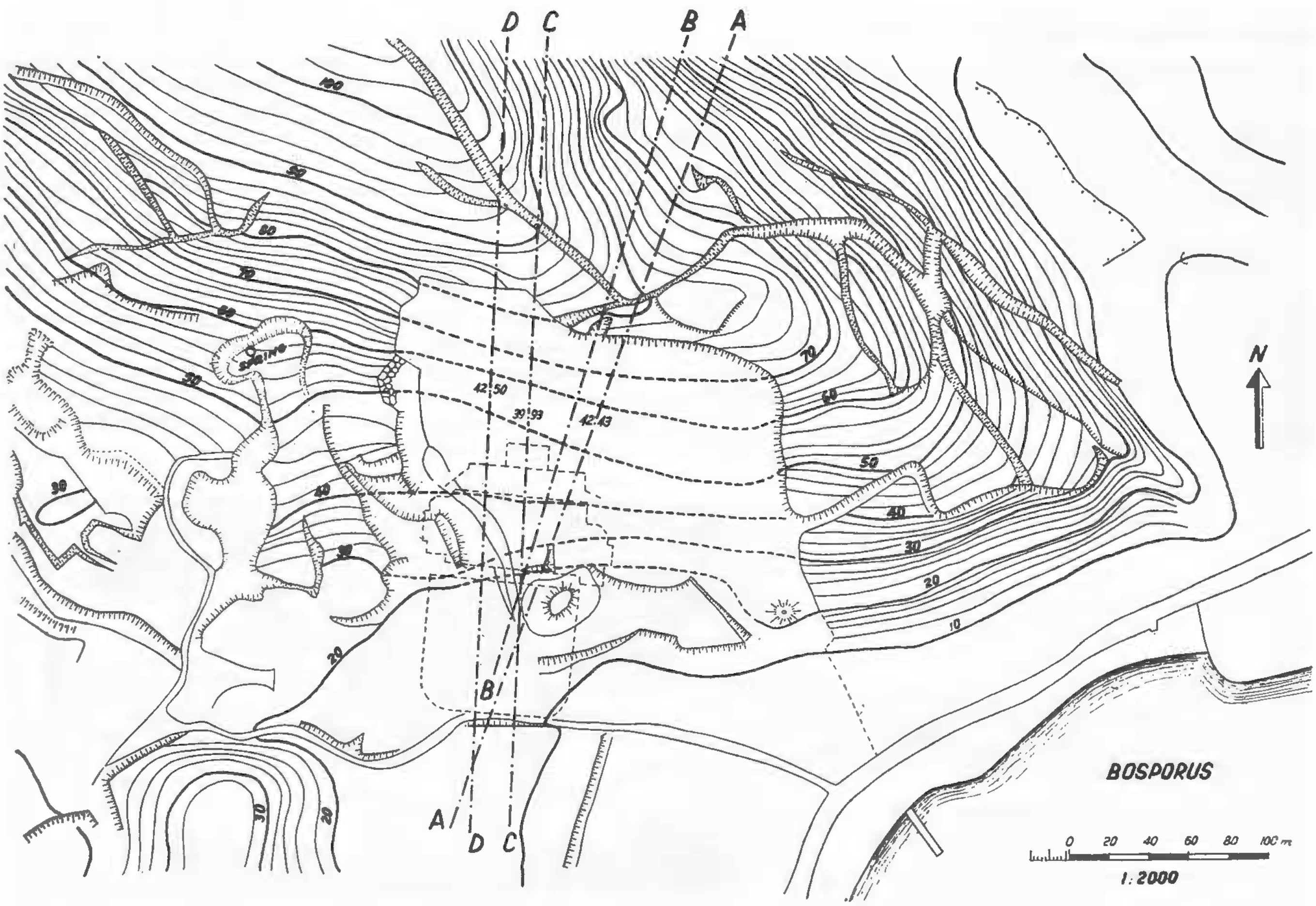

Fig. 3 Map showing the topography of the site some 40 years ago
Topographie du site vers 1916

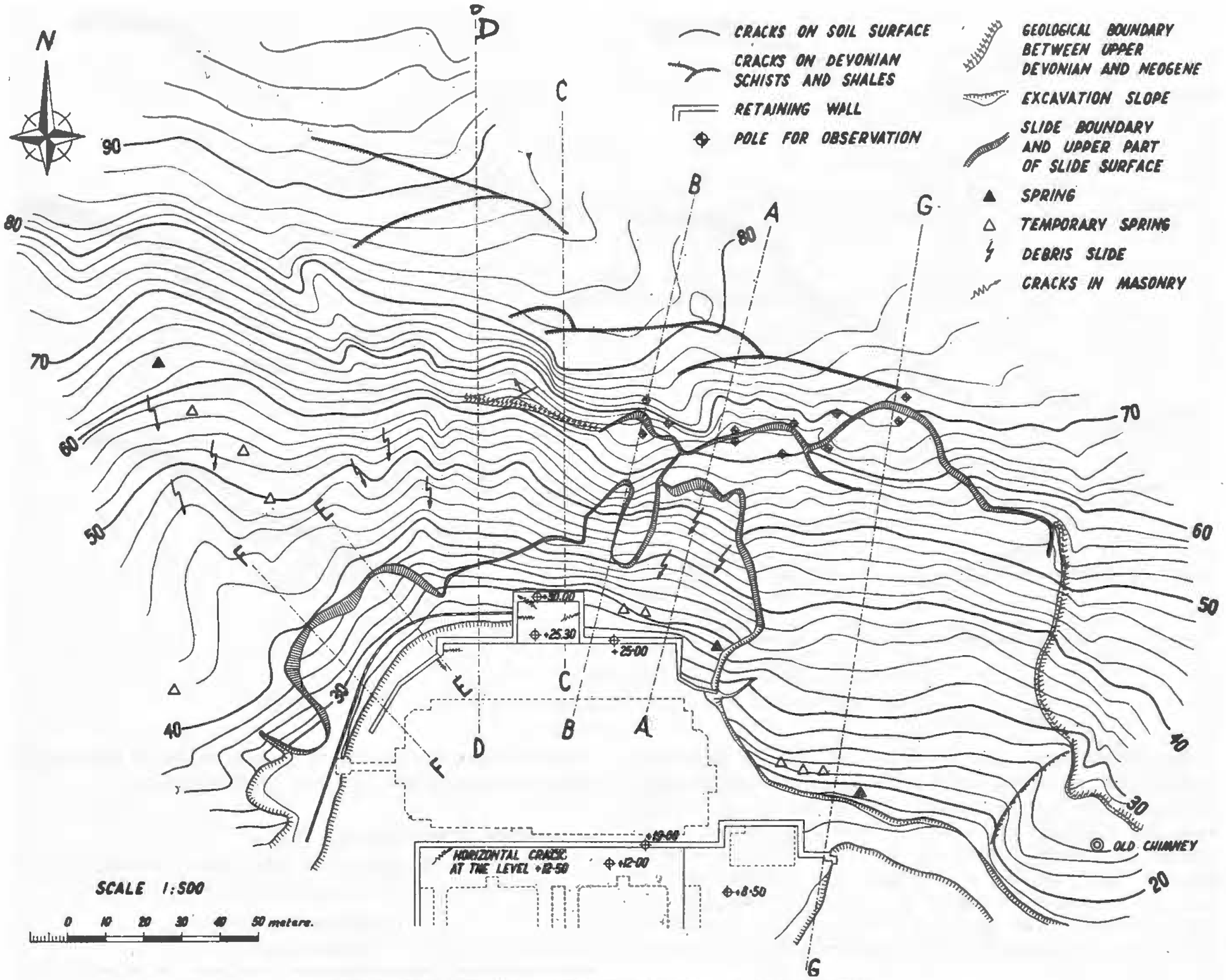

Fig. 4 Map showing the topography of the site in May 1956
Topographie du site en mai 1956

At this stage the author was called upon to investigate the problem and give his opinion about possible remedial measures.

Description of the Site, Soil and Slides

The site lies on the northern part of the European side of the Bosporus. The geological features of the area are described elsewhere (Paeckelmann, 1938). According to the geological maps of the Bosporus (Paeckelmann, 1938; M. Sayar) there is a fault line about 1500 m long running east–west between the contact surface of the upper Devonian and Neogene.

The upper Devonian consists mostly of schisty graywackes and clayey schists which have been strongly fractured during times of tectonic movement. The Neogene (upper miocene) consists of sand, gravel, and clayey layers. The depth of the Neogene at this place is estimated to be more than 80 m. In Figs. 1 and 4 the results of geological surveying are given. At the upper part of the Neogene the soil surface is covered with detritus. The slope of the Devonian has not been determined exactly, but is estimated to be about 45 to 75 degrees. Deep cracks in the Devonian formations run south-east–north-west (see Fig. 4). It seems reasonable to believe that the excavations were also responsible for the formation of these cracks in the strongly fractured Devonian schisty graywackes.

Fig. 7 shows the walls of a new excavation in the place marked *D* in Fig. 9. This vertical bank, before trimming, stood safe during the two past winters. At this place the beds consist of hard fissured grey clay and dense silty yellow sand. A fault cutting these layers is seen in Fig. 7. Grey clay is underlain by dense silty yellow sand which carries water veins, but in general is not saturated. Sample Nos. 4 and 5 were taken from here. Sample No. 3 was taken from the trial pit indicated in Fig. 5, section *A–A*. Here, at a depth of about 3 m there is a slightly sloping joint (its strike and dip is shown in Fig. 8). The surface of this joint shows striations which indicate a sliding movement.

The walls of the 1954 excavation, at the place indicated in Fig. 5, consisted of hard fissured yellow clay. Fissures of this clay show typical slickensides. Sample No. 1a was taken from the pit *efg* (Fig. 6c), and sample No. 1b from behind the retaining wall. For this purpose the hole *abcd* was opened through the masonry (see Fig. 6c). At that time the upper part of the backfill was in a state of slurry, but the soil just behind the hole *abcd* was natural ground with a water content of about 12 per cent. Sample No. 2 was taken from the place indicated in Fig. 5. Hard fissured clayey layers were also weakened by many joints in different directions.

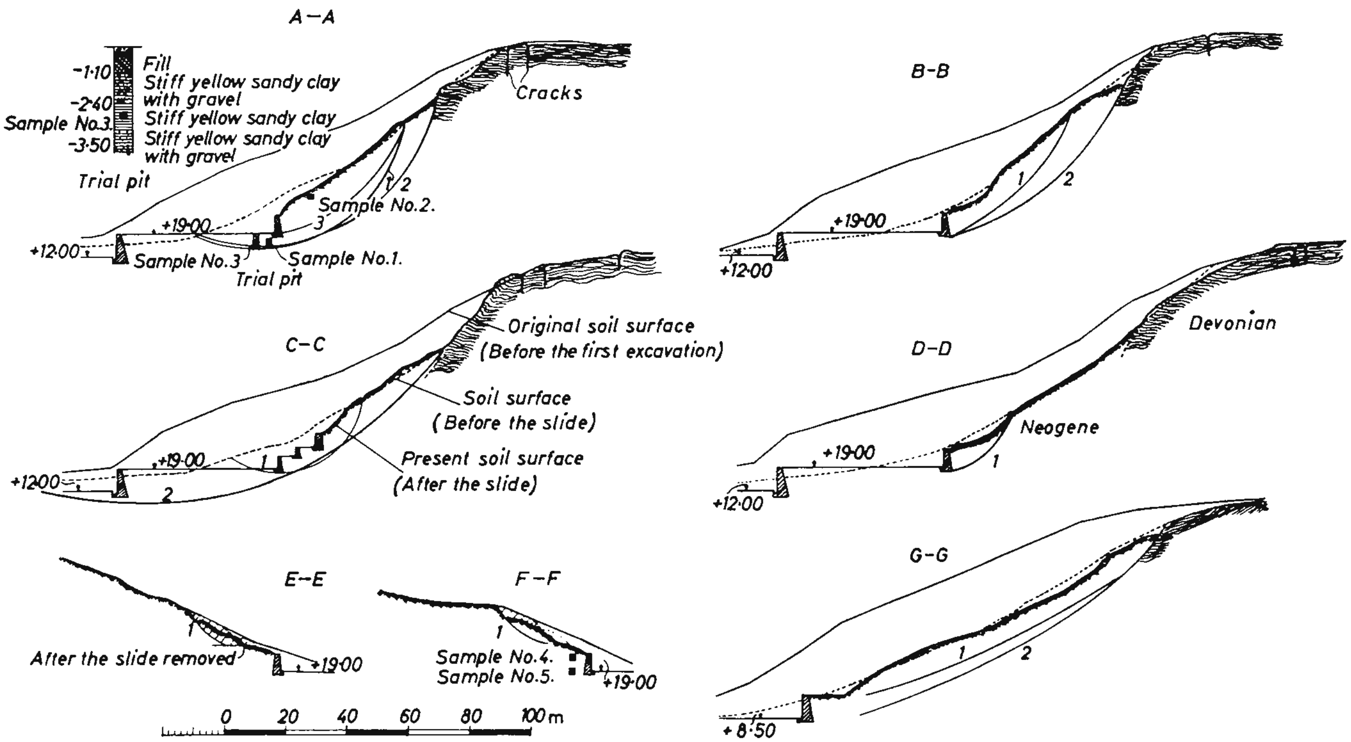

Fig. 5 Cross-sections along the lines marked in Figs. 3 and 4
Coupes transversales de la colline suivant les lignes indiquées dans les Figs. 3 et 4

The ground water table lay below the assumed slip circles (Fig. 5), but at the site there were temporary springs which dried out after the rainy season. Permanent springs or water veins met during the excavations are marked in Fig. 4. In the moving earth masses there was no continuous ground water table. A short distance from a water vein the clayey soil was partially saturated, its degree of saturation lying (approximately) between 0·95 and 0·85. The trial pit excavated to recover undisturbed samples was dry down to the 16 m contour.

Movements Observed

The movements of the masonry were measured until March 1956: at that time the construction of buttresses was nearing completion. The wall movements decreased and became too small to measure with the arrangements installed. Measurements made until March 1956 on retaining walls and concrete floor are summarized in Fig. 6, section *H–H*.

By May 1956 the slope was dry, the temporary springs had disappeared, and 15 buttresses (*B1* to *B15*) indicated in Fig. 8 were completed: still some micro-movements in the masonry were perceptible, and the glass plates installed on some joints cracked. Movements of the earth on the slopes were observed by means of poles marked in Fig. 4. The upper part of the slip surface was seen to be decomposed and strongly fractured schisty graywackes and clayey schists. Soil masses in the slope marked *G–G* in Figs. 4 and 5 show all the characteristic features of a slide: depression, tension cracks and steps on the upper part; bulging and bulging cracks on the lower part. The way to the machine house along the foot of this sliding mass had to be cleared of the advancing earth masses several times during the rainy periods.

The downward movement of the earth masses above the machine house was resisted by the retaining walls of the buildings; but the pressure exerted caused dangerous movements and cracks. Along the sections *E–E* and *F–F* two slides with well-defined boundaries took place as shown in Fig. 9. On 2 March 1956 a detritus slide damaged the roof of the machine house, and débris filled the lower machine house.

Geotechnical Properties of the Soil

Laboratory tests were carried out on the five samples mentioned above and test results are summarized as follows:

Grain size distribution
Granulometrie

Samples	*Type of soil*	*Sand* (%)	*Silt* (%)	*Clay* (%)	D_{10} (mm)	*U*
No. 1a and b	Hard fissured yellow clay	20	48	32	0·0004	36
No. 2	Hard fissured yellow clay	15	55	30	0·0003	33
No. 3	Hard sandy yellow clay	29	46	25	0·0006	35
No. 4	Hard fissured grey clay	28	57	15	0·0015	20
No. 5	Dense silty yellow sand	65	32	2	0·01	18

Atterberg limits (*LL*, *PL*, *PI*), natural water content (*w*), bulk density (γ) and specific gravity (γs)
Limits d'Atterberg (*LL*, *PL*, *PI*), teneur en eau naturelle (*w*) densité apparente (γ) et poids specifique (γs)

Sample	*LL* (%)	*PL* (%)	*PI*	*w* (%)	γs	γ (t/m³)
No. 1a and b	43	26	17	12	2·77	2·2–2·4
No. 2	34	21	13	18	2·72	2·2–2·4
No. 3	36	21	15	14	—	2·2–2·4
No. 4	47	22	25	11	2·73	2·1–2·3

Shear strength—Undisturbed and remoulded samples were sheared with a displacement velocity of 0·65 mm/min. in strain-

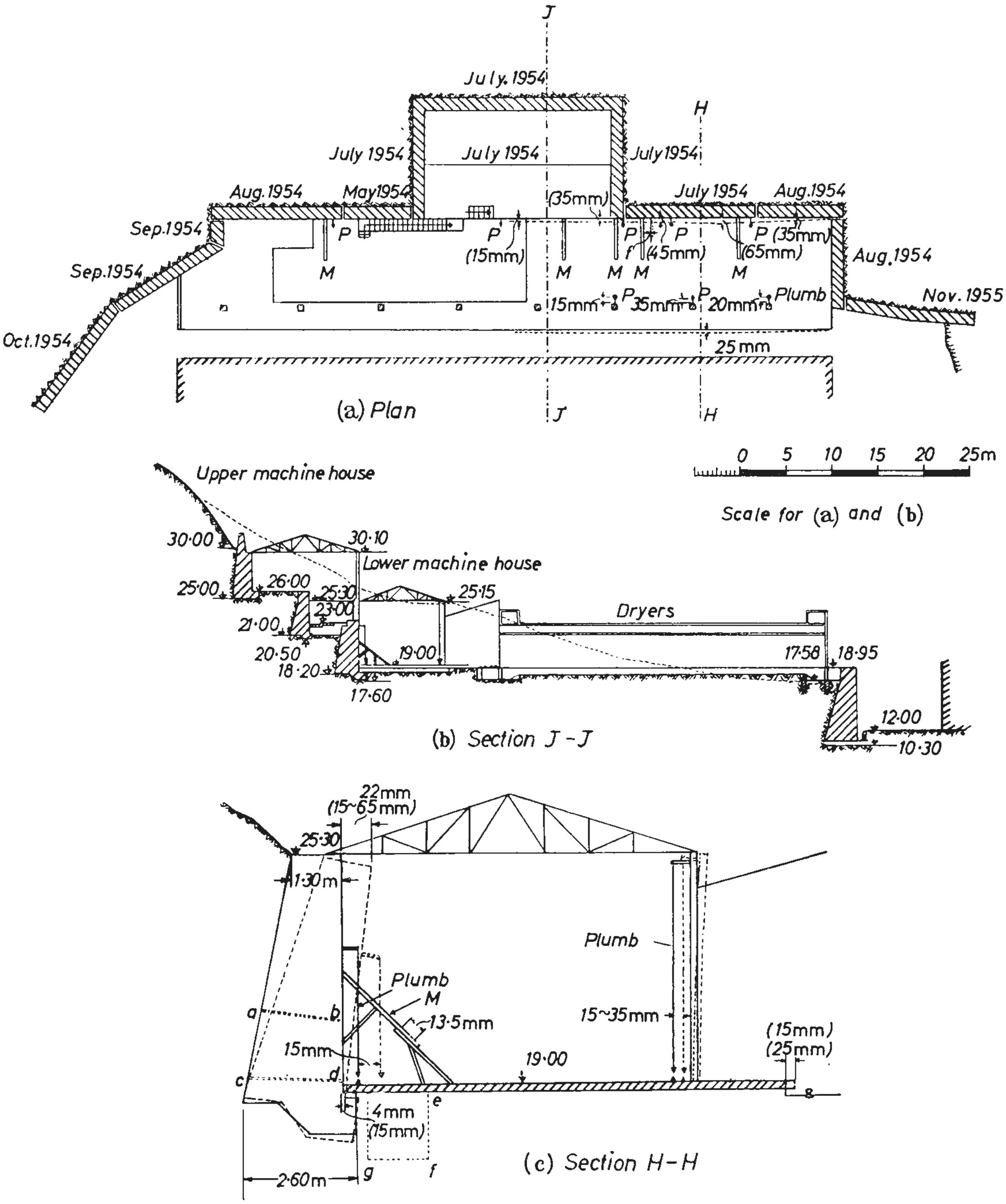

Fig. 6 Movements in masonry and the general layout of the arrangements to measure the displacements
Mouvements de la maçonnerie et dispositif servant à les mesurer

controlled shear boxes after complete consolidation. Prior to loading the undisturbed samples were left to absorb water in the shear boxes. After swelling the height of the samples had increased by about 10 to 20 per cent. Water absorbing capacity depends on factors conditioned by fissuration. When a piece of clay was partly immersed in water it slaked and disintegrated completely in 6 to 24 hours.

Hard fissured yellow clay (*sample No. 1b*)—Undisturbed: Peak values: ϕ = 30 degrees, c = 1·20 kg/cm^2; ultimate values: ϕ = 29 degrees, c = 0·15 kg/cm^2.

Average water content at shear zone: under vertical load p = 1 kg/cm^2, w = 18·70 per cent; under vertical load p = 2 kg/cm^2, w = 14·70 per cent; under vertical load p = 3 kg/cm^2, w = 15·80 per cent.

In the small shear boxes used, the shear strength appears to depend also on the orientation of the fissures. Displacements at shear (peak values) = 4 to 5 mm; displacements at shear (ultimate values) = about 10 mm.

During the tests volume changes also were measured. At failure (peak value) a heave of about 0·2 mm was observed for samples 30 mm thick. After reaching the peak values the volume decreased gradually. With some samples the volume decreased to the original volume.

Remoulded at LL and consolidated: ϕ = 19 degrees, c = 0, displacement velocity = 0·65 mm/min. Average water content at shear zone: for p = 1 kg/cm^2, w = 31 per cent; for p = 2 kg/cm^2, w = 29 per cent; for p = 3 kg/cm^2, w = 27 per cent.

Fig. 7 New excavation made in the place marked *D* in Fig. 9
Nouvelle excavation, au point marqué par *D*, Fig. 9

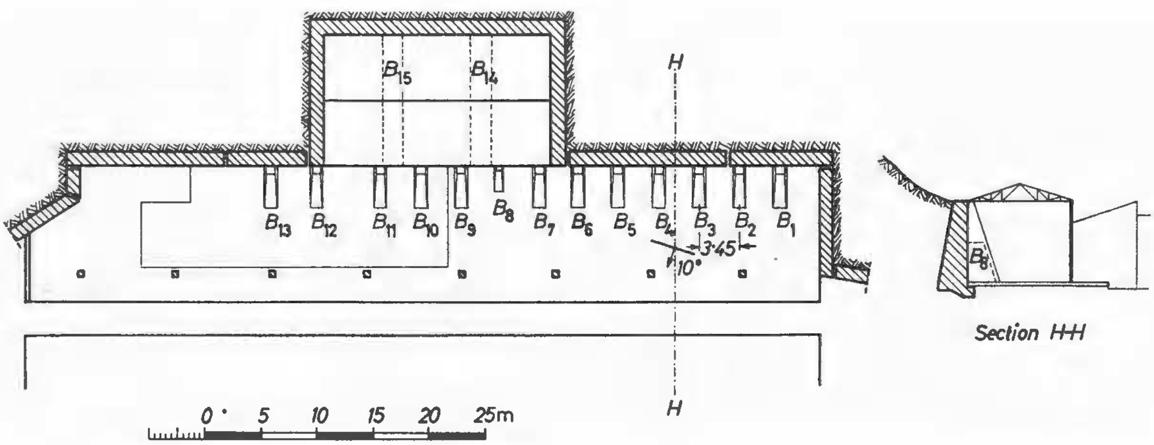

Fig. 8 Plan of the buttresses to strengthen the retaining walls
Plan des contreforts

Average decrease in height was about 1 mm for samples 30 mm thick.

Dense silty yellow sand (sample No. 5)—On this sample triaxial tests were carried out.

(1) For undisturbed samples: $\phi_u = 31$ to 36 degrees; $c_u = 0{\cdot}75$ to $0{\cdot}82$ kg/cm² ($w = 15{\cdot}60$ per cent).

(2) Remoulded at natural water content: $\phi_u = 38$ degrees; $c_u = 0$ ($w = 14{\cdot}83$ per cent).

(3) Remoulded by adding water: $\phi_u = 8$ to 9 degrees; $c_u = 0$ ($w = 25{\cdot}30$ per cent).

Compressibility and swelling capacity—Compression tests in the oedometer were carried out on undisturbed hard fissured yellow clay. Compression and swelling indexes were found for laboratory curves as follows:

Compression index between

$p = 0{\cdot}01$ and $0{\cdot}1$ kg/cm² $C_c = 0{\cdot}012$
$p = 0{\cdot}10$ and 1 kg/cm² $= 0{\cdot}055$
$p = 1{\cdot}0$ and 10 kg/cm² $= 0{\cdot}093$

Swelling index between

$p = 0{\cdot}01$ and $0{\cdot}1$ kg/cm² $C_c = 0{\cdot}064$
$p = 0{\cdot}10$ and $1{\cdot}0$ kg/cm² $= 0{\cdot}062$
$p = 1{\cdot}0$ and 10 kg/cm² $= 0{\cdot}045$

According to these figures the swelling capacity of this clay is very high.

Stability Analysis and Factor of Safety *F*

The slip circles marked in Fig. 5 were chosen on the basis of the factors described previously, and are believed to represent the critical slide surfaces. These slip circles, as well as the shear properties of the soil, were subjected to further investigations and checking. Nevertheless, the factors of safety determined on the basis of these data were considered to be good approximations to the actual *F* values. Above the assumed critical slip circles, even after the rainy periods, there was no continuous ground water table. The degree of saturation of the clay lies between 0·95 and 0·85. Considering these facts calculations were made with total stresses.

Fig. 9 Slides along *E–E* and *F–F* marked in Figs. 4 and 5
Glissements suivant *E–E* et *F–F*, Figs. 4 et 5

Table 1
Stability analysis and factors of safety (*F*) for most probable slip circles
Analyse de stabilité, et facteur de sécurité pour les cercles de glissement les plus probables

ϕ	C kg/cm²	Section	Circle No.	Before the excavation	After the excavation
30	1·2	A–A	1 2	3·16 2·61	2·78 2·47
		C–C	1 2	4·25 4·28	3·64 4·57
		G–G	1 2 3 4	— — — —	2·76 2·52 2·52 2·26
29	0·15	A–A	1 2	1·61 1·39	1·29 1·28
		C–C	1 2	1·86 2·08	1·19 2·06
		G–G	1 2 3 4	— — — —	1·46 1·28 1·33 1·34
29	0	A–A	1 2	1·40 1·18	1·08 1·12
		C–C	1 2	1·54 1·82	0·85 1·75
		G–G	1 2 3 4	— — — —	1·28 1·11 1·17 1·22
19	0	A–A	1 2	0·87 0·76	0·67 0·70
		C–C	1 2	0·95 1·13	0·54 1·08
		G–G	1 2 3 4	— — — —	0·70 0·69 0·73 0·76

The results of the stability analysis are shown in Table 1. According to Table 1 the average values of the factors of safety after the excavation for different laboratory values of ϕ and c are as follows:

For ϕ = 30 degrees and c = 1·20 kg/cm² $F = 3{\cdot}60$
ϕ = 29 degrees and c = 0·15 kg/cm² $F = 1{\cdot}40$
ϕ = 29 degrees and c = 0 kg/cm² $F = 1{\cdot}20$
ϕ = 19 degrees and c = 0 kg/cm² $F = 0{\cdot}74$

A value of ϕ between 19 and 29 degrees would give $F = 1$.

Shear strength values calculated from the slip circles in Fig. 5 gave the following s values:

Sections	Circle No.	Shear strength required for the limiting stability: Before the excavation	Shear strength required for the limiting stability: After the excavation
A–A	1 2	s = 0·70 kg/cm² 0·91 kg/cm²	s = 0·75 kg/cm² 0·93 kg/cm²
B–B	1	—	0·30 kg/cm²
C–C	1 2	s = 0·38 kg/cm² 0·46 kg/cm²	s = 0·42 kg/cm² 0·52 kg/cm²
E–E	1	—	0·26 kg/cm²
F–F	1	—	0·34 kg/cm²
Estimated from standing vertical bank of 10 m height for ϕ = 0 and for ϕ = 25			0·55 and 0·35 kg/cm²

After shallow detritus slide a lump of clay among the debris was examined. The pocket penetrometer reading at the outer surface was 2 to 3, and at the inner part of the lump 10 to 12. These readings correspond approximately to unconfined compressive strength values of 0·5 and 2 kg/cm² respectively.

Conclusions

There is much evidence that the equilibrium of the earth masses in the slopes investigated has been disturbed, and after

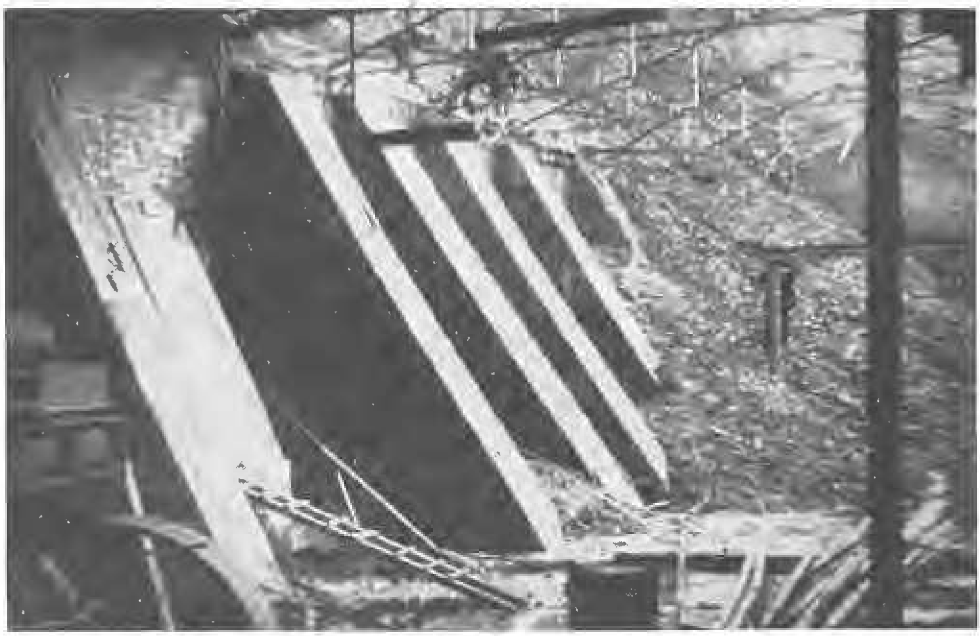

Fig. 10 Inside view of the lower machine house after detritus slide
Vue interieur de salle des machines après l'éboulement de debris

a first failure the earth masses came to a second temporary equilibrium. There are indications that these earth masses will continue in their downward movement as soon as the shear strength becomes smaller than the sliding force. Because of the open cracks on the surface of the sliding masses rain and snow water will find access to the fissures.

On the basis of this reasoning it seems justifiable to determine the factor of safety of these slopes with a ϕ value obtained on remoulded samples. A study of the F values given above suggests that in stability analysis for fissured clays it would be reasonable to disregard the cohesion and to determine the angle of shear strength by means of consolidated slow shear tests on undisturbed samples considering only the ultimate s values. This conclusion confirms the results of the investigations on fissured clays made by HENKEL and SKEMPTON (1955).

On the other hand slow shear tests made with undisturbed and remoulded fissured clays from another locality gave approximately equal values for ultimate shear strengths. On the basis of this result, and considering that also in this case slower tests would give the same result, it seems justifiable that slow shear tests on remoulded samples can be taken as a basis for stability calculations in connection with fissured clays under the ground water table.

According to the results found above, the factors of safety in masonry and in sloping soils are not sufficient; therefore the following remedial measures can be recommended:

(1) to load the excavated foot of the slope;

(2) to drain the sloping area by hard core drains;

(3) to establish new retaining walls with a well-designed backfill drainage, and

(4) To provide reference points for periodic observation of the probable movements due to deeper sliding surfaces and deep cracks in Devonian schisty graywackes and clay schists on the upper part of the slopes.

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