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IV c 3 CONTROL OF THE STABILITY OF A SLIDING SLOPE IN A RAILWAY CUT NEAR WETTEREN

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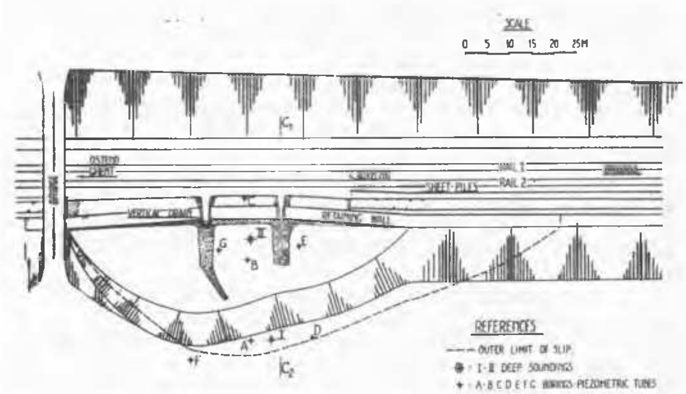
INTRODUCTION.

In the first months of 1943 a slip occurred in the railway cut, on the line Brussels (Midi) - Ostend in the vicinity of the kilometer indicator 40.2000, near Wetteren. This cut was excavated in the early years of the nineteenth century, to a depth of about 10 meters, with side slopes of about 8/4.

The site of the slip is shown in figure 1, in which a dotted line gives the limits of the area of slip. A cross-section through the sliding slope is seen in figure 2. A crack and subsidence near the top of the slope were observed. The approximate depth of the tension crack which had developed prior to the slide, was about 1 meter. Near the toe of the slope an upward movement of the rails had taken place. So when the failure occurred, in the median part of the slip zone, a difference of height of about 0,15 m was found between the outward rail 1 and the interior rail 2. The limit of the slide was visibly located between the two tracks.

Some previous movements had taken place at this point and had inspired some anxiety to the engineers of the S.N.C.F.B. Various measures had been taken in order to stabilize the slope. As can be seen in figures 1 and 2, at the toe of the slope a retaining wall in concrete had been erected, with the hope to maintain the profile. In front of this wall a mass of stones had been placed in order to provide a supplementary support for the wall. At some places a row of sheet-piles was found at the toe of the wall. However, it has appeared that the retaining wall was not founded sufficiently deep in order to have an effective effect, whilst the construction of the wall led to an increase of the waterpressure in the slope. Afterwards large openings were made in the wall and filled with drainage materials. Just behind the wall the slope was considerably flattened. But movement continued and in a further effort to remedy this situation, in 1928 a vertical circular drain was placed in front of the wall, what helped temporarily to reduce the waterpressure in the slope.

In spite of all these measures a definite slip took place in 1943. It was then decided upon to perform a complete soil investigation and further to analyse the stability of the slopes with a view on remedial measures which could be adopted.



Plan of slip in a railway cut near Wetteren

FIG.1

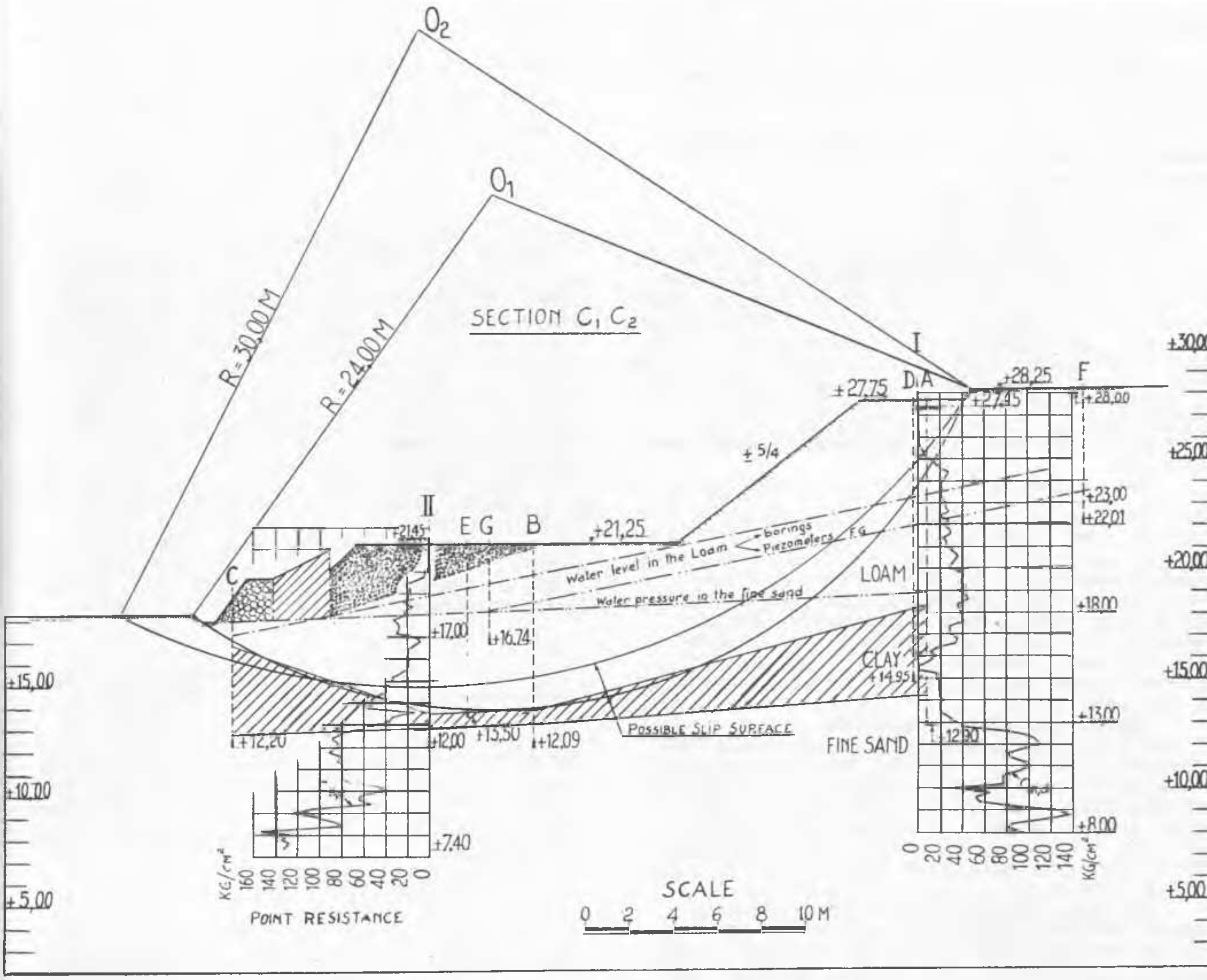
SITE EXPLORATION.

As a first exploration of the site two deep sounding tests were carried out. The location and the results of these tests are given in figures 1 and 2. This exploration was supplemented by 7 borings in order to discover the sequence of strata and to obtain undisturbed samples from which the physical and mechanical properties could be determined. The changes of the ground water-levels were recorded in 7 piezometers. The position of the borings and the piezometers are shown in figure 1.

As revealed by the deepsounding tests and by the boring the natural strata on a depth of 20 meters below the original ground surface comprised:

Boring A.
- from + 27,16 to + 18,46 : yellow loam, fairly sandy in its upper part.
- from + 18,46 to + 14,41 : blue clay.
- from + 14,41 to + 12,00 : fine sand, lightly clayey.

At deepsounding I, this last sand layer has been recognized to the level + 8,00. It has also been established that the thickness of the blue clay was very different from point to point. As shown in figure 2. where the clay



Cross-section of slip near Wetteren

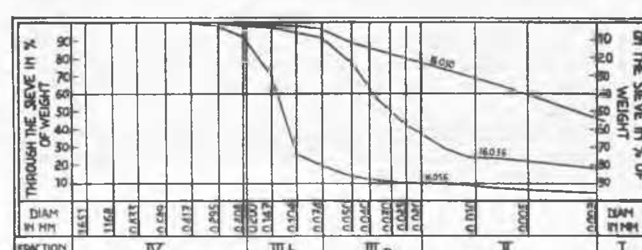
FIG.2

layer is represented by a shaded area, the upper limit of this stratum is notably lower in the median part of the slope, where the thickness of the clay is reduced to about 1 meter.

LABORATORY EXAMINATION.

Hereafter the properties and some particularities of the different soil strata are briefly described.

In figure 3 is shown the grain-size distribution of a typical sample taken in each of the encountered layers. The Atterberg limits and the plasticity-index of these samples are given in the following table:



Granulometric size

FIG.3

Number of sample	Strata	Liquid limit %	plastic limit %	plasticity index
16036	loam	30,7	18,4	12,3
16050	blue clay	130,0	41,6	88,4
16056	clayey fine sand	28,8	19,8	9,0

The plasticity index of the loam and the fine sand is respectively smaller than 25 and 15. In the clay it ranges from 60 to 100.

The percentage of organic matter or chalk is almost without significance. In some samples of blue clay, this percentage was, however, lightly above 2 %.

With respect to the volumetric weight of examinated soils the following mean values have been obtained:

loam: 2,01 t/m^3
blue clay: 1,8 t/m^3
fine sand: 1,93 t/m^3.

The natural water content in the loam and the fine sand was generally greater than 20%. It may also be mentioned that the natural water content only lightly exceeds the plastic limit.

The dry weight of the loam and the fine sand ranges from 1,55 to 1,65 t/m^3, that of the clay hardly reaches 1,25 t/m^3. The percentage of voids of the loam and the fine sand is mostly smaller than 40% whilst that of the clay is higher than 50%. The most samples were saturated.

The variation of the cone resistance $C_{k,o}$ with the depth is illustrated by figure 4. A dotted curve gives also the variation of the natural water content. It may be seen that the highest values of the cone resistance are found in the clay stratum; these values indicate a clay with a firm consistency. On the contrary the loam and the fine sand present very low resistances; nevertheless lightly greater values are found in the capillary zone of the loam.

Unconfined compression tests, carried out on the clay samples, have given an angle of internal friction φ ranging from 10° to 20° (mean value = 15°) and a shearing resistance located between 0,17 and 0,59 kg/cm^2 (mean value = 0,35 kg/cm^2). It must be mentioned that the lowest values of the shear strength are obtained in the upper part of the clay, in boring C made at the toe of the slope.

The shear resistance of the different strata was principally determined by testing the undisturbed samples in the triaxial compression apparatus. The results of such a test are expressed in figure 5. The test results are summarized in the following table, wherein the mean and the lowest values of the shear constants, obtained in the loam and the clay are given.

It was found that in the clay the lowest shear strength was obtained for the samples taken in the upper zone of the stratum. It was also seen that the consolidation progresses very slowly in the clay, but more quickly in the loam.

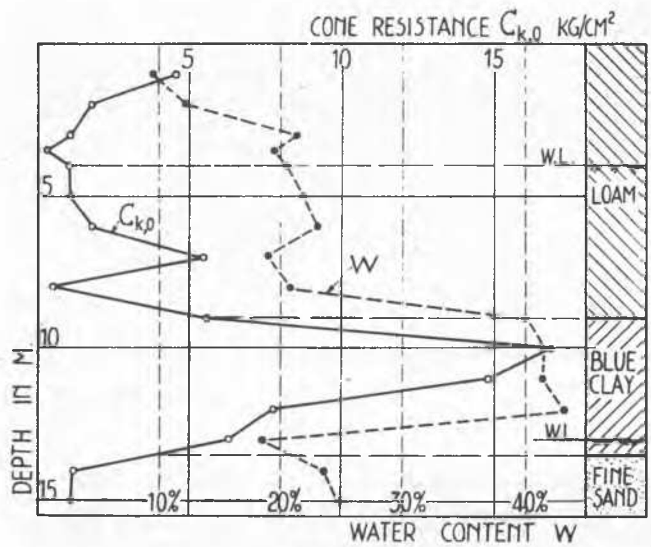
By carrying out permeability tests, the following limits of the coefficient of permeability were obtained:

Strata	Coefficient of permeability k in cm/sec.
loam	from 10^{-5} to 10^{-6}
blue clay	from 10^{-8} to 6×10^{-9}
fine sand	from 10^{-4} to 10^{-6}

OBSERVATIONS IN PIEZOMETRIC TUBES.

From observations in the piezometers, it was possible to draw the time-ground water level curves shown if figure 6. The measurements concern a period of about two months. Although no considerable changes were found, it may however be seen that during the summer 1943, some decrease of the water pressures have occurred. More important are the differences of the water-levels measured between the top and the base of the slope. (see also the cross-section in figure 2)

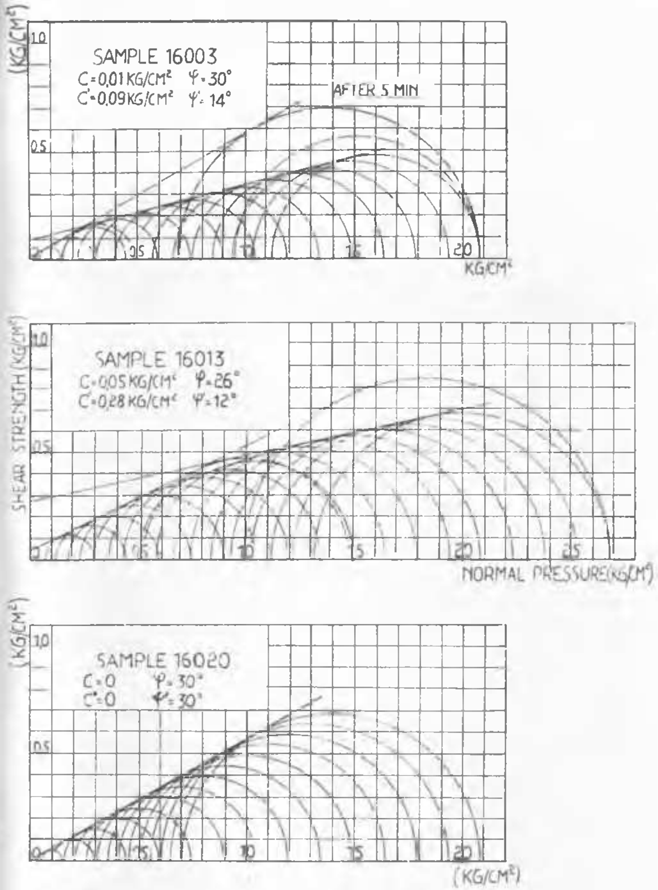
The measurements in the piezometric tubes A, B and C, whose ends are placed in the fine sand, indicate that the watertable in this stratum is artesian. The mean hydraulic gradient is very slight, and is of the order of 1/20, between the tubes A and B. The highest level measured in A reaches at + 19,00.



Variation of cone resistance and water content with depth

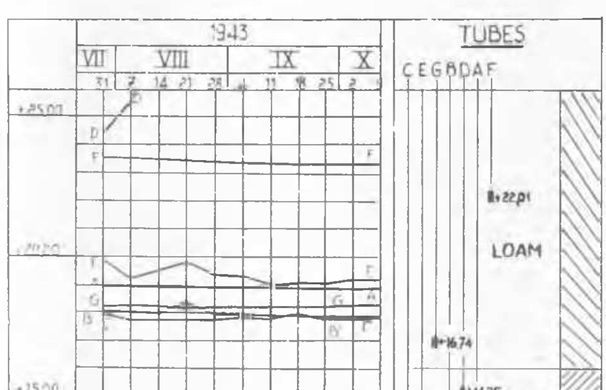
FIG.4

Stratum	Value	Angle of internal friction φ	Angle of apparent friction φ'	True cohesion c in kg/cm^2	Apparent cohesion c' in kg/cm^2
Loam	mean value minimum value (sample 16000)	30° 35°	14° 15°	0,02 0	0,10 0,06
Clay	mean value minimum value (sample 16028)	25° 23°	12° 9°	0,08 0,02	0,23 0,12



Results of cell tests

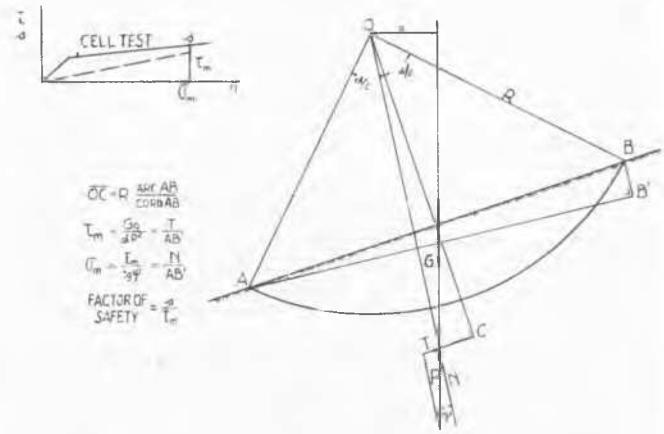
FIG.5



Variation of ground water pressure.

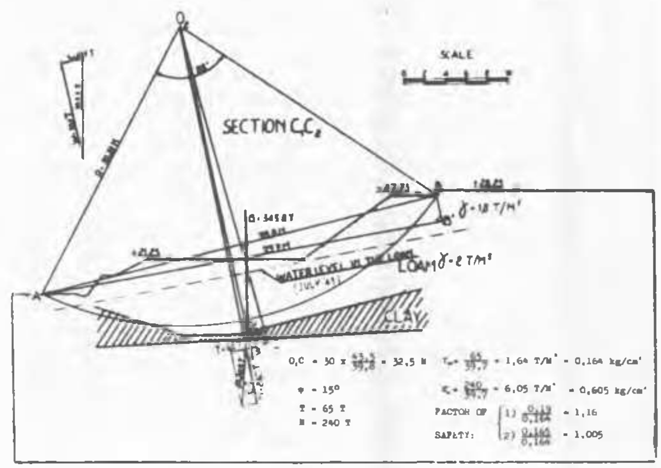
FIG.6

The water-levels obtained in the tubes F and G, whose filters were placed in the loam, show an hydraulic head of more than 5 meter. Between the tubes F and G, this upper water-table had a mean hydraulic gradient of about 1/5. In F, thus at the top of the slope, the highest measured water-level was + 23,50. It must also be pointed out that the water-levels recorded in the boreholes, about one month before the observations in the piezometric tubes,



Principle of stability analysis

FIG.7



Example of stability analysis

FIG.8

were found about one meter above the latter.

The piezometric tube E placed in the blue clay has given an overpressure of about one meter in relation to the corresponding tube G placed in the loam. Two measurements performed at the tube D, which was also placed in the clay stratum, indicated also an overpressure of about 1 meter. This overpressure in the clay is likely in connection with the great pressures, which may exist in the loam during the rainy periods of the year.

THE ANALYSIS OF THE STABILITY OF THE SLOPE.

On the basis of the test results and the observations in the piezometric tubes, stability calculations were carried out in order, firstly to find a physical explanation of the movements which occurred and secondly to determine the measures which would be taken to prevent further failures.

STABILITY COMPUTATIONS.

The displacements of soil which were observed in the field, and the location of the zones of weakness found by testing the undisturbed samples make it possible to locate the slip surface with some accuracy. This surface could be approximated by one or other of the two circular surfaces shown in figure 2. These surfaces have respectively as centre, the points O_1 and O_2 and as radius, R = 24 meter and 30 meter. The former follows the upper limit of the clay layer, the latter travels over a great part through the under layer of the loam.

The stability computations made in connection with these rotational slip surfaces are based upon an approximative method suggested by M. Huizinga. The principle of this analysis is given by figure 7. It consists in calculating average values for the normal pressure σ_m and the tangential pressure τ_m along a chosen slip circle. The comparison between τ_m and the available shear strength s, which may be determined by triaxial compression tests, gives an indication of the margin of safety of the slip, with respect to the particular circle chosen.

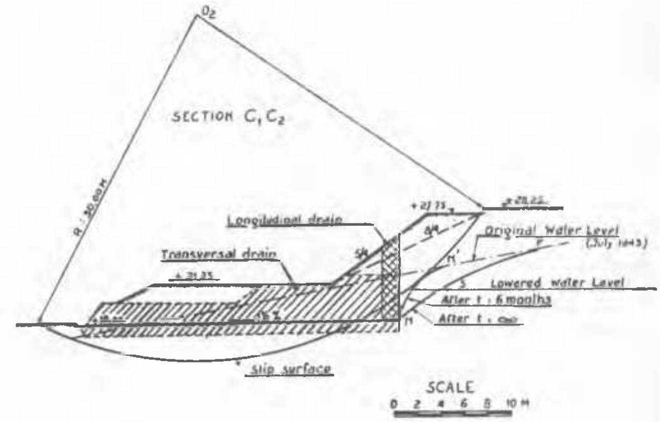
An example of such an analysis, in relation with the circular slip O_2 , R = 30 meter is given in figure 8. The mean pressure σ_m is 0,605 kg/cm^2, whilst the mean value of τ_m is 0,164 kg/cm^2. With respect to the mean value of s obtained in the loam, the factor of safety is 1,16. If we consider the lowest values found in the loam (sample 16.000), the factor of safety is only 1,005. Similar calculations which have reference to the slip circle O_1 , R = 24 meter, have shown that in relation with the most unfavorable shear strengths obtained in the upper zone of the blue clay (sample 16028), the factor of safety was found to be equal to 1,10. It is of interest to note that the calculations which led to the safety values given above, assume that the water pressures in the loam correspond with the most unfavorable water-levels measured in the first days of July 1943.

Whatever may be the shear resistance to which can be referred, the results of the calculations show obviously, that in the assumed conditions, the soil masses limited by the chosen circular slip surfaces were in a state of equilibrium very close to the critical one. Then it is evident that in rainy seasons, when the water-level in the loam may rise considerably, the disturbing forces can exceed the restoring ones, and failure may occur.

REMEDIAL MEASURES.

As a result of the site investigation and of the stability analysis, a knowledge of the mechanism of failure has been obtained, and it can be clearly seen that the objects of remedial measures must be to decrease the water-pressures in the loam. Firstly a decrease of the water-pressure means an increase of the effective pressure along the slip surface, and consequently an increase of the shear resistance. Secondly if the water-table at the top of the slope is maintained at a lower level, the hydrodynamic forces, which are acting upon the soil mass of the slope are reduced. In order to increase rotational stability, the first means for attaining this object is to lower the water table. It is evident that by flattening the slope a complementary increase of the stability can be obtained.

Calculations indicate that if the phreatic water-level in the loam could be lowered at the level + 18,00 (figure 9), the factor of safety would be increased by 30 %. On the other hand, if the slope at the top would be 8/4 instead of about 5/4, an increase of 20% would be possible (fig. 9). Together these measures might lead to an increase of stability of 50%.



Ground-water lowering by means of drains

FIG.9

In order to lower the water table in the loam, it is necessary to drain the soil. For instance the lowering of the water table can be accomplished by constructing within the soil at the top the slope, a longitudinal drain. With the object to establish an adequate position for this drainage, an estimation was made about the position of the lowered water-table with a drain which base would be located at the level + 18,00. In these computations, it was assumed that the layer of loam had a constant and uniform coefficient of permeability, namely k = 10^{-6} cm/sec. The curve NN' in figure 9 gives the position of the water-table after a drainage time of 6 months. The curve NSP corresponds to an infinite time of drainage. In fact, the average permeability of the loam may be greater than what was allowed in the computations; besides, in some samples a coefficient of permeability of the order of 10^{-5} cm/sec has been found from tests. Therefore, the curves NN' and NSP are to be considered as upper limits.

The construction of a longitudinal drain was found to make out a very expensive solution. Therefore it was decided to substitute the longitudinal drain by a system of transversal drains, which would penetrate to a sufficient depth into the earth of the slope. Three of these drains were really executed, at intervals of about 25 meter. The filter materials of the drains have been judiciously chosen (gravel and coarse sand) in such a way that the loam particles were hold back and could not be washed through the voids of the drain. As complemental measure, material was removed from the top of the slope, so that a more flat profile was obtained. It seems that the taken measures proved successful, for since 1943 no further movement of the slope had taken place.

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