Full Scale Field Test on a Slope Progressive Failure

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SYNOPSIS : In order to obtain the mechanical behaviour parameters of the red structured clays from the Danube - Black Sea Canal and to estimate the behaviour of the slopes cut in such clays, an experimental programme was carried out. A checked failure was provoked for a slope dug in red fissured clays. The paper presents the results of the field investigations and the laboratory test regarding the, characteristics of the structured clays, as well as the in situ measurements during the experimental programme. The results of these measurements are compared with those obtained by numerical symulation using a computer program.

INTRODUCTION

The problem of the Dobrogean red clay behaviour in deep excavated slopes, as well as that of the measures to be taken in order to inssure the stability is known as early as before the first World War. It has became the major preocupation of many technical experts who achived some consolidation works along the cliff of Black Sea in Constantza harbour area and close to the beach or surveyed the performance of deep trenches for the railway which led to the harbour (Zahariade,1934; Stănculescu, 1960 ; 1963).

The red clays from the Dobrogean Plateau area along the Danube - Black Sea Canal (fig.1) by their nature, composition and structure,create special slope stability problems for the deep excavations which are susceptible to failure due to the material flow under the action of an intense drying followed by a moistening induced by local infiltrations and precipitations. They are strongly structured clays, with fissures and friction slide faces, covered by manganese and iron oxides. In contact with the atmospherical agents, the red clays are fragmented into polyedrical glomerules (Stănculescu et al.,1980).

The deep excavations cause the relaxation of the mean compression stress around the excavations and the increase of the shear stress. For these stress combinations, the clay behaves as an overconsolidated material,which proves the peak strength values for low shear strains, and significant lower residual values for large strains.

The peculiarities of the red clay behaviour as well as the decompression by excavation, rendered evident the possibility of stability loss, by the slopes carried out into these clays, by progressive yielding according to the mechanism described by Bjerrum (1968).

The initial horizontal forces acting in the ground are removed by excavation from the base of slope whereas their values stay high inside the slope. Therefore the ground will tend to more laterally starting from the toe zone which is most unbalanced. The lateral displacement

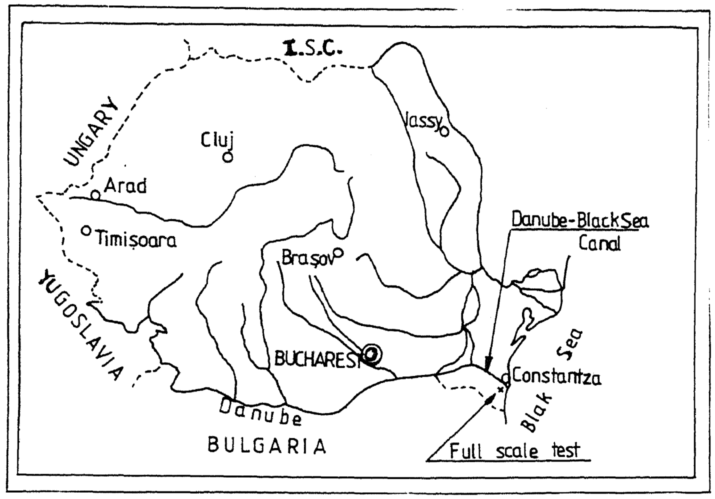

Fig.1 Full scale test position

of an element situated at the slope toe determines a decrease of the elastic horizontal force from the upstream of that element and an increase of the tangential stresses in the slide plan. The important decrease of the horizontal force at the upstream limit of the slope toe element unbalances the next element which might get the state of the first element, and, in this way, the process is iterated with the following elements. The slope yielding is a regressive process taking place upstream from the toe until the horizontal forces are balanced by the strengths mobilized along the slide surfaces.

The progressive yielding of the red clay slopes during the excavation has been studied in detail at natural scale, by controlled rupture experiment in a chosen profil on the right bank of the Canal at Km 61+000, initiated by the Civil Engineering Institute, the Design Institute for Transportation Engineering and the Study and Design Institute for Hydroenergy from Bucharest,

EXPERIMENTAL PROGRAMME

The tests and measurement, carried out in the field and laboratory at the portion of slope to be investigated (fig.2) were :

- bore holes located in three typical profiles, noted A, B and B' for taking undisturbed samples and establishing the lithologic profils of the experimental zone (F symbol - fig.2) ;

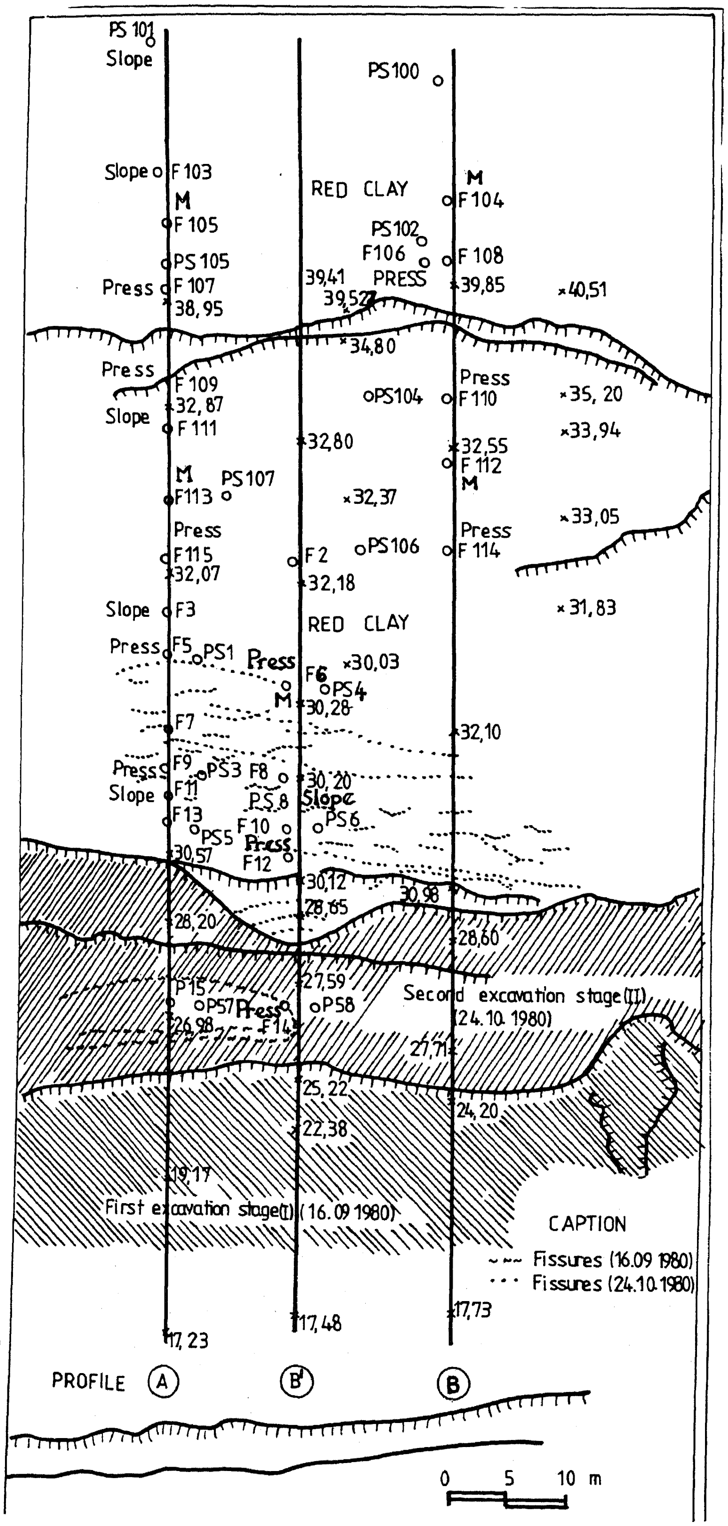

Fig.2 Experimental programme

- instrumentation of the experimental profiles, with the purpose of surveying the slope behaviour during the experiment ; the above mentioned boreholes were subsequently adapted to the horizontal displacement measurements by slope indicator (SLOPE symbol - fig.2). Beside these boreholes other were carried out to try to establish the eventual slide surface (M symbol) ;
- surface markings made by means of mortar bands cast into a square surface of 10m side on the slop
- marking of the slope surface by topografic and photogrametric marks for the surveillance of the slope surface displacements ;
- field tests to determine the characteristics of the layers encountered ; some boreholes were drilled for pressuremeters tests (PRESS symbol). Furthemore, static penetration tests were carried out (PS symbol) ;
- laboratory tests to determine the identification properties and the deformability and yielding characteristics of the red clays ;
- two stage excavations at slope toe toghether with the surveillance of the lateral displacements during the experiment ;
- comparison between the field measurements and the results obtained by numerical modeling of the progressive yielding.

GEOLOGIC STUDY

The field investigations revealed the existence in the studied profiles of a cuasi-horizontal Quaternary formation slightly sloping south east sedimented on a sometimes fissured, limey Sarmatian conglomerate with greenish clay and cuasi-cemented sand intercalations. The Quaternary formation is 20÷22 m thick and contains, in differentiated forms, a 4÷5 m thick overburdening sediment of loessoid nature, with a 2-4 m thick, yellow loessoid clay transition (lehm) up at the lower part to the 10-12 m thick, red clay horizon . The samples collected from the boreholes revealed the non-homogenity of the red clay horizon, with clayey facies variations on vertical and in extension. Red-dark red clay packs are noticed alternating with clayey bands rich in limey concretions. An about 1 m thick clayey loess continuous layer was rendered evident within the red clay horizon. The red clay has an intense structural microfissuring in horizontal slightly inclined and vertical position and slickensides in particularly horizontal, slightly inclined position, inexistent in the vertical fissures. All the above assertions, may lead to the conclusions that along its geologic history, the clayey formation might have been overconsolidated and, after overloads removing, the horizontal stresses which remained larger than the vertical ones might have produced internal shears and distruction of the diagenetic links. In that part exposed to the seasonal climatic cycles, the clay forms a thin glomerular mobile, typical crust. Having a high drainage capacity due to the fissures.The investigated horizon was lacking the aquifer at the experiment data (June÷October, 1980). Between the red clay and the limey base a 1÷2 m thick structure consisting of clayey limey elements and structured greenish clay is encountered as a transition formation. The soil profile revealed by the boreholes and field tests is presented in figure 3 for the three investigated profiles.

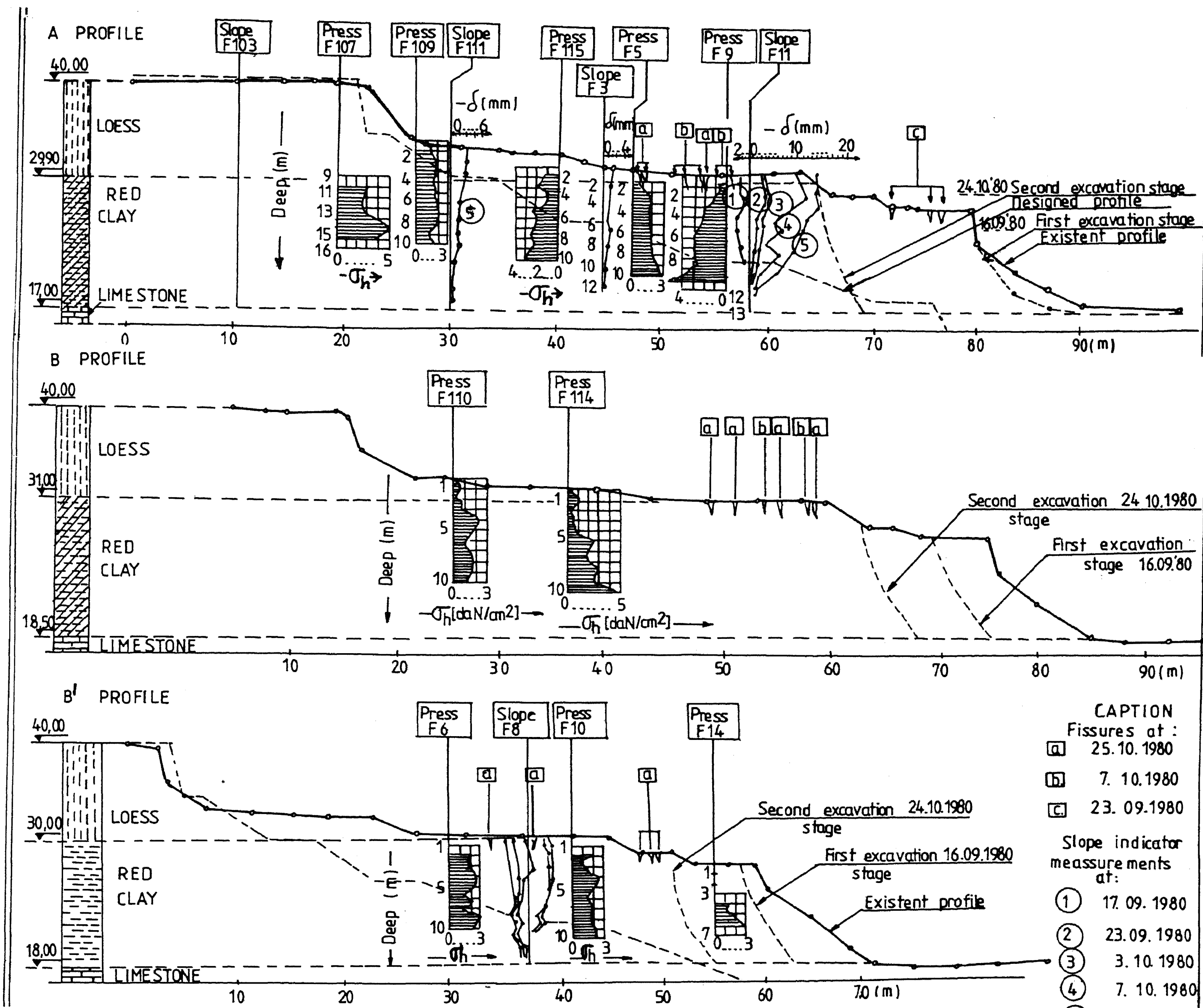

Fig.3 Profiles A, B and B'. Field tests results

FIELD TESTS

The red clay deformability in horizontal direction was investigated by pressuremeter tests. The tests were achieved by a Menard type of pressuremeter, by a 60 mm diameter probe and a pressure-volumeter connected by plastic tubes through which water and gas are applied. The measurements gave the range of possible values for the coefficient of lateral stress at rest, $K_o = 0.42 \div 0.95$. By adopting the correlations between the pressuremeters data and conventional shear test results, and processing the data obtained, the ranges of values for the shear strength parameters resulted : $\emptyset = 10 \div 20^o$; $c = 20 \div 60$ kPa. Also from the processing of the measurements data, resulted the range of values for the Young's modulus E, on horizontal direction $E = 10{,}000 \div 30{,}000$ kPa. In order to determine the "in situ" characteristics of the ground, static penetration tests were performed, with a cone having the base diameter of 36.50 mm and the angle of 60^o, thrust into the ground at a constant speed of 2.5 cm/minute.

LABORATORY TESTS

In order to determine the physical and mechanical characteristics of the clays found in the studied profiles certain laboratory tests were carried out. The clay deformation modulus in the field at the decompression on horizontal direction caused by the excavation was determined by the performance of oedometer tests in which the clay sample taken from the sampler tubes, horizontally as to the soil profile was subjected to a loading equal to the horizontal stress in the field, and then, the sample was unloaded by stages and the values of edometric deformation moduli were determined at decompression for each unloading stage (fig.4). It was noticed that the deformation modulus was significantly reduced with the applied pressure which is in accordance with the pressuremeter tests results, carried out in the field. Direct reversible shear tests were carried out to determine the

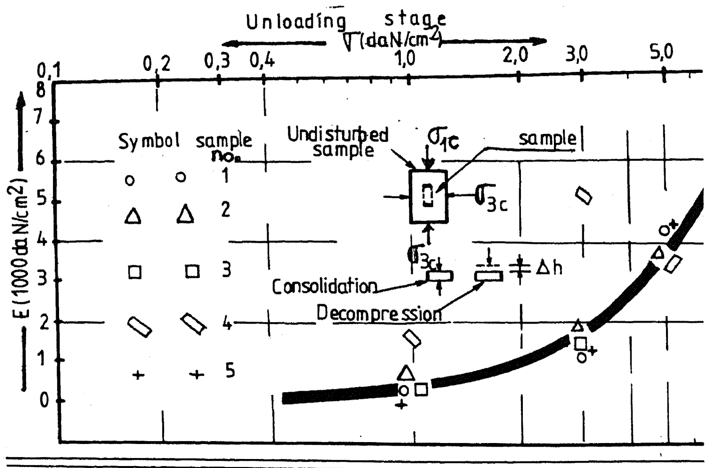

Fig.4 Oedometer tests. Values of deformation moduli at decompression

shear strength. The samples were consolidated at the vertical effective field stress and then they were left unloaded at different values of the vertical stress and allowed to decompress under those reduced vertical loads and finally sheared reversibly reaching a stabilized value of the shear strength (fig.5). The obtained curves of shear stress, τ - relative shear displacement δ, for the two kinds of structured clays with a peak and a residual values are typical for the overconsolidated clay behaviour. On the figure 6 are presented the curves of variation with δ for the friction angle and for the coession.

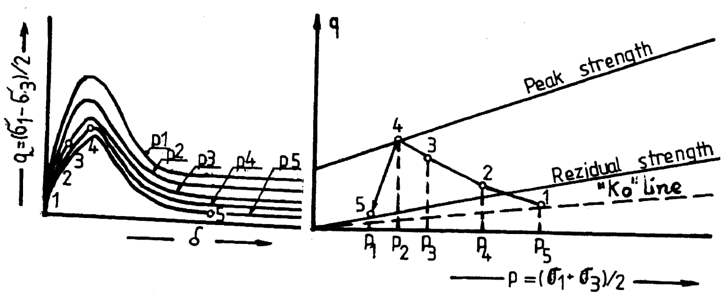

Fig.5 Direct reversible shear tests

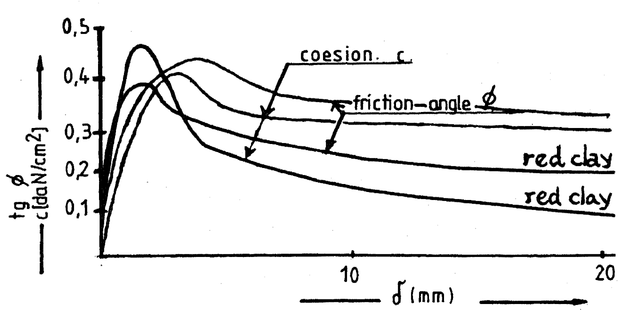

Fig.6 The curves of shear stress - relative shear displacement for the red and greenish fissured clays

Table 1 presents the ranges of the shear strength parameters determined for the two type of fissured clays from the plateau zone of the Danube - Black Sea Canal.

Table 1 The ranges of shear strength parameters for the red and greenish fissured clays

CLAY TYPE			RED CLAY		GREENISH CLAY	
	φ, c	M.U.	minimum	maximum	minimum	maximum
Shear strength parameters	φ peak	(°)	21	22	19	22
	c peak	daN/cm²	0,30	0,45	0,41	0,67
	φ rez.	(°)	12	12	8	16
	c rez.	daN/cm²	0,00	0,00	0,00	0,00

CONTROLLED RUPTURE EXPERIMENT

The controlled failure process of a slope in red clays (fig. 2) started at the date of September 5, 1980. The full scale field test consisted of two stages of excavation at the base of the slope followed by the surveillance of displacements fissures occurence and if eventually, loss of stability. The first stage of toe excavation from East to West (following the sequence of profiles A, B' and B - fig.2) ended on September 16, 1980. As the excavation was local at first, near the profile A, then extended towards profiles B' and B, in profile A at about 10 m upstream the excavation limit, the first fissures appeared, being noticed on 23 September 1980. At the same time, the only indication of lateral displacement was obtained in a borehole equipped with slope indicator at about 20 m upstream the excavation limit in profile A. The measurements carried out in September 23, 1980 indicated downstream displacements to the Canal axis (N-S) of about 4 mm, which had their maximum values at the slope surface and vanished at about 10 m of depth. Figure 3 presents the situation of excavations fissures and lateral displacements recorded during the controlled excavation at the toe, in profile A. The excavation continued in the second stage by excavating in the same direction from East to West (profiles A, B',B) a 20 m portion of red clays upstream, as for as close to the limestone surface. During the second excavation stage the fissure occurence was recorded on October 7, 1980, as a combined effect of the first excavation stage (time effect) and of the progress of the second excavation stage. The fissures recorded at the date of October 7, 1980 extended in all the 3 profiles controlled by measurements. The upstream extension was maximum in profile A and minimum in profile B (fig.2). In figure 3a,b,c indicates the lateral displacements measured on the slope indicator which increased progressively downstream between September 23, 1980 and October 23, 1980 reaching values of about 16 mm after the second stage completion. The measurements in different boreholes from profile A show that the displacements increase downstream towards the excavated limit and get lower towards the boundary of the excavation area.

During the progress of the second stage of excavation an upstream extension of the fissures position was recorded in all the 3 profiles.The slide surface, formed as a consequence of the slope toe decompression due to the second excavation stage was found by linking all the depths where the lateral displacements measured on the slope indicator vanish. It can be seen in fig 3 that the slide plan outcrops to the slope toe at the limit between the structured clay and limestone. The fissure occurence (downstream-upstream as well as their progressive opening with time showed that the slope decompression took place upstream from the toe indicating a progressive yielding mechanism. The clay shear strength at peak is exceeded by the unbalanced lateral thrust and the clay suffers large displacements in its slide surface, the offered strength being the residual one, which can no longer balance the lateral forces. Thus the decompression is propagated upstream.

SIMULATION OF SLOPE PROGRESSIVE YIELDING BY COMPUTATION

The simulation of the behaviour of slopes in structured clays, considering their particular features, was made by using a method of slope stability analysis in overconsolidated clays, taking into account the stress-strain ($\tau - \delta$) relation determined by laboratory tests (Athanasiu,1980). The slide plan is considered known and the sliding earth mass is divided in slices. The results of the calculations determined by using a computer program (Athanasiu & Chirică, 1982) for the experimental profile A are presented synthetically in figure 7. There are presented the variation of the shear stresses effectively mobilized during the decompression process, τ, and of the shear strengths corresponding to the calculated slide displacements. The ratio between the surface of τ_f diagram and that of the τ diagram represents the global safety factor for slope stability problem. Also, there are presented the values of the shear displacements in the slide plan as well as the horizontal forces between the slices for the two stages of excavation.

It can be seen in Table 2 that, as the excavation progresses the safety factor gets close to 1.0, whereas an extending portion from slide surface reaches the residual strength value.

Table 2 The calculated values of safety factor during the full scale field test

Experiment phase	Calculated safety factor, F_s
Initial situation	1.33
Stage I 23.09.80	1.32
Stage II 25.10.80	1.02

The displacements calculated in different excavation stages quantitatively reproduce the distribution of displacements measured by inclinometer.

Admitting that the initial distribution of horizontal stresses on the slices limits is trapese-shaped, and the stress decompression take place uniformly on height, the calculation

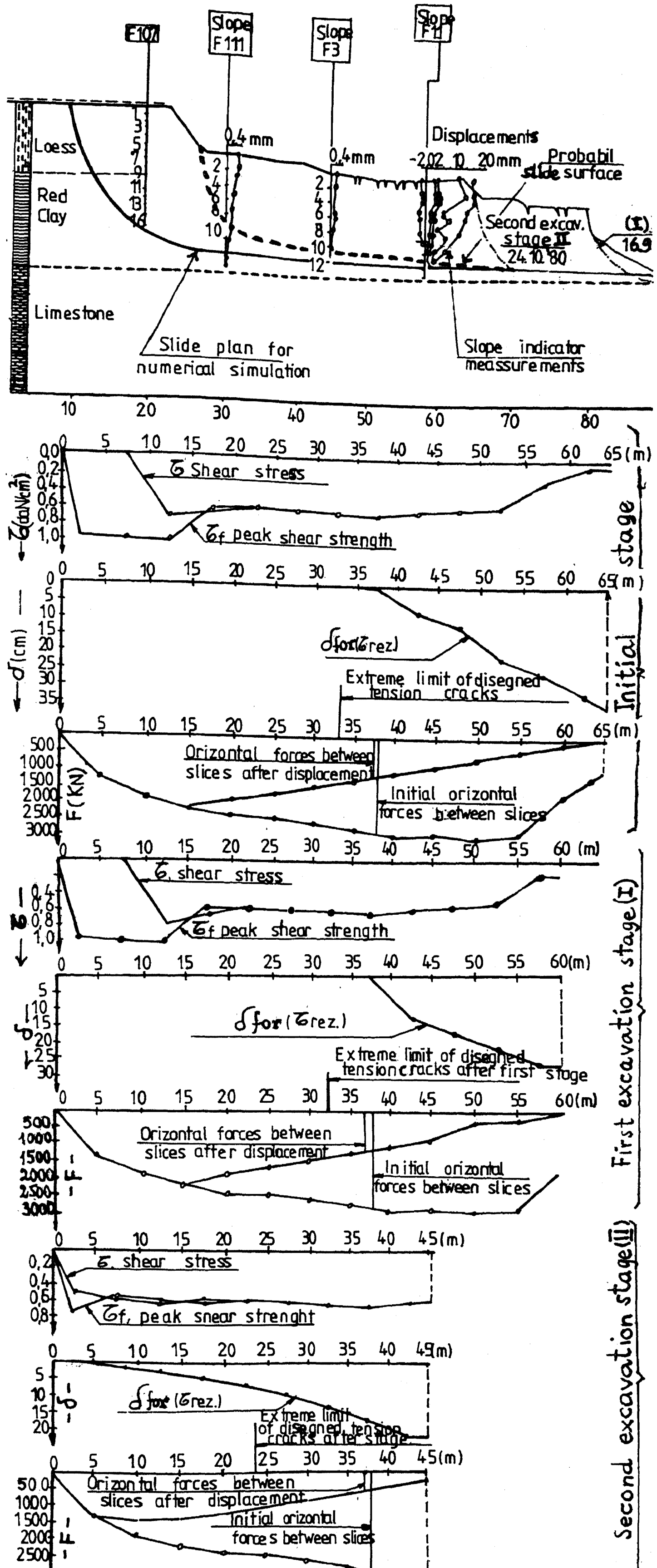

Fig.7 Simulation of slope progressive yielding by computation. Results

could estimate the limit of the zone in which traction fissures might occur at the upper part of the slope. The extension of the calculated fissure zone is qualitatively in accordance with the observed extension.

CONCLUSIONS

From the examination of the results obtained by the proposed calculation method one concludes that the method simulates progressive yielding phenomena caused by the excavation decompression what remains essential in obtaining accurate results, is the correct determination by field and laboratory tests of the mechanical soil parameters.

REFERENCES

Athanasiu C. (1980) - Non-linear slope stability analysis. Proc.3rd Int,Symp.on Landslides New Delhi.

Athanasiu C., Chirică A. (1982) - Computer program for stability analysis of excavated slopes in structured clays. Proc.3rd Nat.Symp.on Application of computers in Civil Engineering. Sibiu.

Stănculescu I. (1960) - Some problems concerning stability of clay slopes. Sc.Bull. of Civil Engineering Institute, no.7, Bucharest.

Stănculescu I. (1963) - Sicherung der Gelaude - rutschungen in stadtgebiet von Konstanza. Technische Universitat, Dresden, 12.Heft pp. 489-499.

Stănculescu I., Popescu M., Athanasiu C., Chirică A. (1980) - Stress-strain and strength characteristics of structured clays from the Dobrogean Plateau area. Proc.6th ECSMFE, Varna, pp.307-322.

Zahariade P.A. (1934) - Constantza Town. Protection and consolidation of North - East slopes.