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Trigger mechanism of progressive landslides analysis and explanation

L'analyse et l'explication de la mechanism declencheur pour les glissements de terre progressives

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ABSTRACT
Abstract text Conditions for the occurrence and development of slope instability in macrostructured dilatant clayey soils are investigated, both experimentally and theoretically. A computing procedure based on the finite element method adapted to nonlinear and dilatant media, was elaborated to evaluate the state of stress and strain in sloping earth masses having a dilatant mechanical behavior. In this paper are presented some major landslides from Romania with corresponding conclusions

RÉSUMÉ
Texte du résumé Dans cette oeuvre on parle sur l'investigation des conditions ou se produirent les phénomènes d'instabilité pour les argiles macrostructures dilatantes. Ils sont présentes les aspects théorétiques et expérimentales. Aussi ont présent une procédure de calcul fondée sur le méthode des éléments finîtes adapte pur les sols avec un comportement nelineaire et avec la manifestation de la dilatance. Ils sont présents des exemples des grands glissements de terre de la Roumanie avec les conclusions correspondantes.

1 INTRODUCTION

A special case of progressive failure is given by the structured clays. The first to contribute to this problem was K. Terzaghi in 1936 who referred to the stability of slopes with natural structured clays.

In his paper he recognized the difference between soft clays having an intact natural structure and no crack or fissures, and hard clays characterized by polyhedral aggregates surrounded by shiny surfaces.

In this sort of clays, belonging to normal or overconsolidated soils, the shearing displacements leads to relative motions of the aggregates along the surface of the fissures together with their opening. These relative movements bring about mechanical swelling or dilatancy. This process, typical for macrostructured clays, appears under low values of spherical stresses. The extent of the dilatancy depends definitely on the size of the deviator stress. Due to this peculiarity, the dilatant macrostructured clays, also called glomerular clays, yield to shearing in those zones where their resistance is locally diminished, and not in the zones where the tangential stress is the greatest. This process is also facilitated by the fact that the appearance of dilatancy brings about the growth of humidity through suction, in the areas mechanically inflated.

According to Matsuo and Kamon (1973), the macroaggregates, as macrostructure's elements have typical sizes, greater than 50μ, seen by microscopic view or by eyesight. For example, the figure 1a represents a normal view of the London clay, while in the figure 1b a macroscopic view (X30) for the Oxford clay is presented. One can see the macroaggregates and the well defined fissures network (Rowell, 1972).

As a result of the above mentioned local failure mechanism in the case of structured clays by contrast with other soils without a specific structure, there is not a shearing surface but a zone in which the aggregates still uncrushed, suffer dislodging, rotations and relative slides along the discontinuity surfaces.

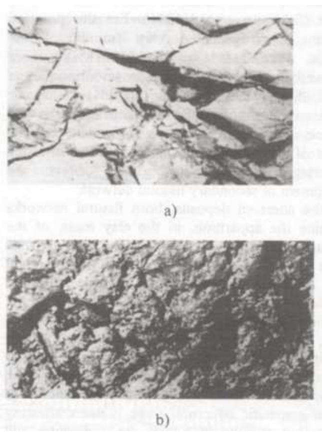


Figure 1. Macrostructured clays: a). London clay-eyesight view; b). Oxford clay-microscopic view (x30) (after Rowe 1972)

2 ROMANIAN CASE STUDIES AND GEOTECHNICAL TESTS RESULTS

The red clays from the Dobrogea Plateau, due to their nature, composition and structure, create special slope stability problems. The properties of this kind of soil have been studied since the beginning of the century (Stanculescu, 1960) A typical example are the extended landslides, which has been recorded for years, in several urban areas, along the Black Sea shore (fig. 2).

Figure 2. The locations of the studied case histories

Figure 3 shows the schematic section of these progressive sliding phenomena, that take place through the red clay, which lies at the bottom of a loess stratum. The water table level is situated within the loess stratum, 4~5m over the red clay stratum.

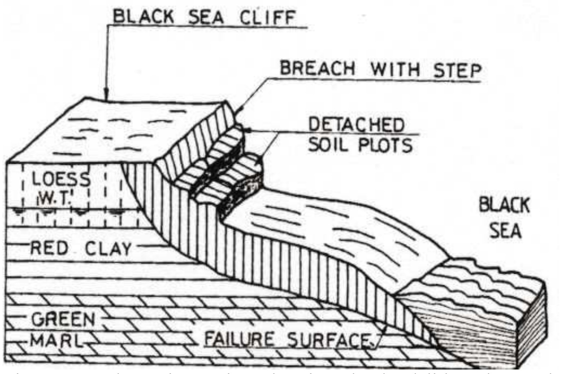


Figure 3. Schematic section showing the landslides along Black Sea coast

Initially, the landslide was caused by erosive processes at the toe of the slope. According with the scheme in the figure 3, the cyclic evolution of the sliding has the following stages:

a. The formation of a weak zone right under the loess stratum and the detachment of a new plot of soil.
b. The recent detached plot pushes progressively the soil mass on the soil towards the sea, and so on.

The second stage of the sliding process gives the detrusive character of these landslides.

Other case history, registered in the spring of 1993, refers to a slope instability which occurred in the Galati-Tulucesti cliff area (Stanculescu et al.1995), affecting a railway (fig. 4,5). The occurrence of vast landslides coincided always with spring thaw periods or intensive and lasting rainfalls. Soil displacements started (fig. 8) for each stage of instability, in the same way as in the previous case, by the detachment of a plot of land, from the edge of the Covurlui plateau.

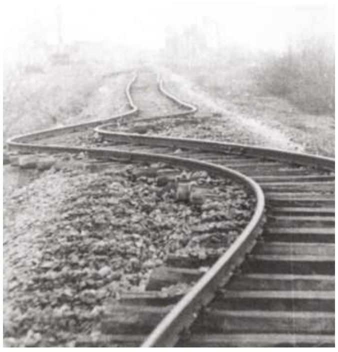


Figure 4. Lateral displacement of the railway

Figure 5. Railway failure in the bulging zone

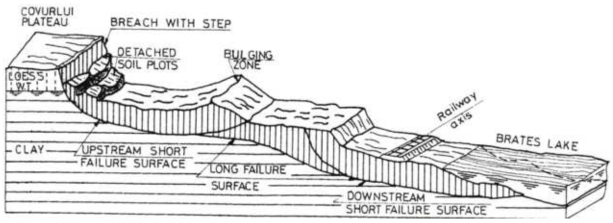


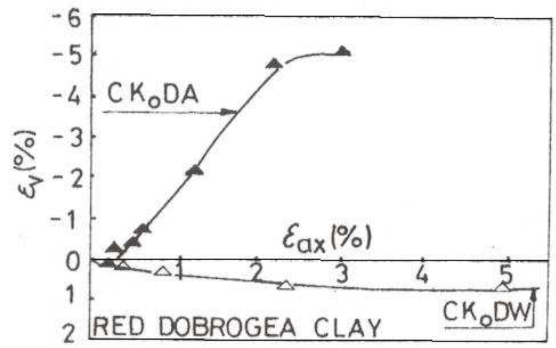
Figure 6. Suggested section corresponding to the Tulucesti landslide

In next stage, this pushes progressively the soil previously accumulated on the slope. Upslope short shear surfaces (fig. 6) are producing sliding movements of the instable mass, with a building zone appearance, while long shear surfaces are causing horizontal displacements in the railway zone, and into the Brates lake. The landslide has also a detrusive character on the upper slope part.

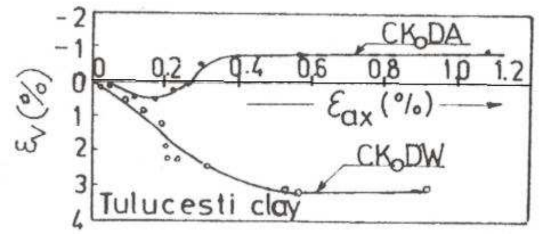
As one can observe, the locations of the two studied landslides are similar from geological point of view. Also, their suggested mechanism features a weak zone, right under the loess permeable stratum, where the water access from a free water source is facilitated. Taking into account these remarks, special laboratory tests for both structured mentioned clays were performed (fig. 7 and 8).

The graphs are typical for structured clays, leading to the following remarks:

a. the existence of a constant ratio between the deviatory stress, q, and the spherical stress, p, from which the dilatancy starts manifesting.
b. the dependence of the dilatancy volumetric strain, ($-\varepsilon_v$), on the deviatory stress.



a)



b)

Figure 7. The volumetric strain variation during shearing in triaxial tests for red Dobrogea (a) and Tulucesti (b) clays

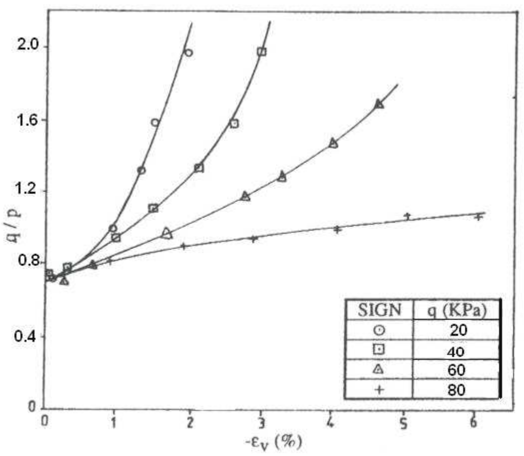


Figure 8. Stress – volumetric strain data for modified standard drained tests

These results emphasize that the extension of the dilatancy zone, can be determined, so long as the stress state within the soil mass is known.

It should be mentioned that the weak zones, previously defined as the failure trigger for the discussed landslide phenomena, are included in the more extended dilatancy zone.

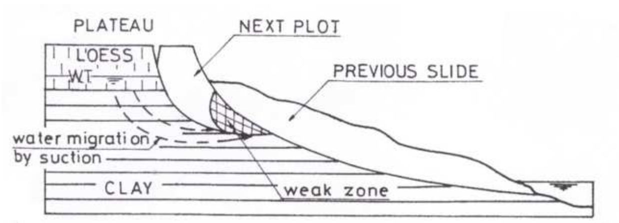


Figure 9. The trigger mechanism of studied landslides

The above mentioned laboratory tests have shown that for the dilatant macrostructured soils the volumetric deformation ε_v has two component elements: $(\varepsilon_v)_s$ due to the spherical mean stress p $p=(\sigma_1-2\sigma_3)/3$ consequence of the macrostructure being broken, and $(\varepsilon_v)_D$ mechanical swelling depending on the spherical stress and especially on the deviator stress ($q=\sigma_1-\sigma_3$)

3 PROPOSED CALCULUS METHOD AND RESULTS FOR "TULUCESTI" LANSLIDE

The aim is to define the "weak" zones in which dilatancy appears, according to the stresses values. It is very important to find out those zones, because they are parts of the sliding surface, most likely. To simulate the behavior of the soil in the plane state of strain, the hyperbolic model is used. (Konder, 1963; Duncan et al., 1980).

For determining the parameters of this material, shown in figure 2 (Izumi et al.,1976) the tangent modulus E_t, bulk modulus B and dilatancy modulus H are calculated with relations (1), (2), (3)

$$E_t=\left[1-\frac{R_{f1}(1-\sin\phi)(\sigma_1-\sigma_3)}{2c\cdot\cos\phi+2\sigma_3\sin\phi}\right]^2\cdot K_E\cdot p_a\cdot\left(\frac{\sigma_3}{p_a}\right)^{n_E} \quad (1)$$

$$B=K_B\cdot p_a\cdot\left(\frac{\sigma_3}{p_a}\right)^{n_B} \quad (2)$$

$$H=\left[1-\frac{3\tau_{oct}R_{f2}(1-\sin\phi)'}{2\sqrt{2}\cdot}\right]^2 K_H\cdot\left(\frac{\sigma}{p_a}\right)^{n_H} \quad (3)$$

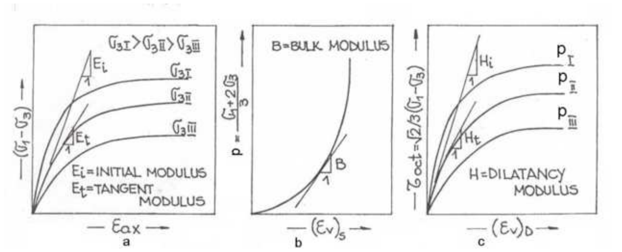


Figure 10. The stress - strain relations for the two volumetric strain components (after Izumi et al 1976)

where n_E, k_E, n_B, n_H, R_{F1}, R_{F2} are hyperbolic models parameters and p_a is the atmospheric pressure.

In those areas of the slope, where the ratio $q/p>D_R$ according to relation (1) an extra volumetric strain will appear (Fig. 10 c)

$$(\varepsilon_v)_D=\frac{\tau_{oct}}{H} \quad (5)$$

So relation (1) may be put down as:

$$\varepsilon^*=\frac{p}{B}-\frac{\tau_{oct}}{H}=\frac{p^*}{B} \quad (6)$$

where p_m is the spherical mean stress and p^* is the same stress, corrected.

Taking into account the physical importance of dilatancy, we can write:

$$p^*=p-\frac{\tau_{oct}B}{H} \quad (7)$$

Assuming that dilatancy appears as an isotropic phenomena (Frank, Guellec, 1974) the correction of stresses, $D_C=(\tau_{oct}-B)/H$ in the current calculus path is considered to be a state of initial stresses and a new vector of nodal loadings corresponding to it. In this way we can also get the deformations occurring with the corrected stresses, for all the finite elements. At the same time using criterion $q/p>D_R$ we can identify the dilatancy zones along the slope.

For Tulucesti landslide the above presented method was used. The calculus profile divided in finite elements can be seen in the Figure 11.

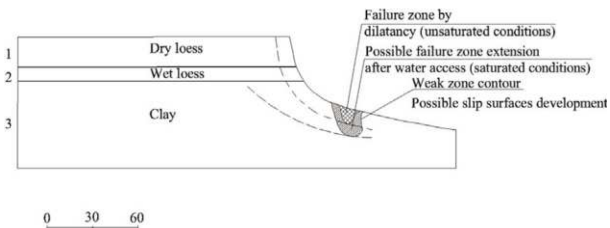


Figure 11. Calculus profile for Tulucesti landslide and computation results

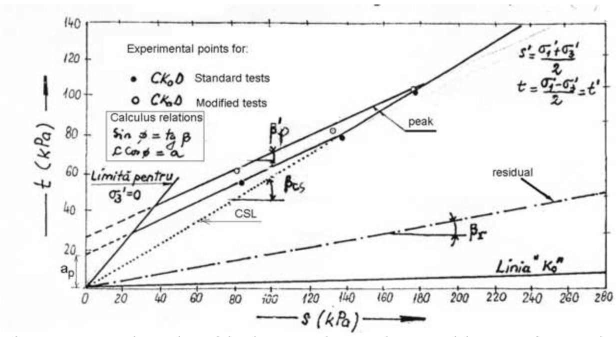


Figure 12. Peak and residual strength envelopes with CSL for "Tulucesti" clay

To find the extension of the weak zones and after that the failure areas the above mentioned triaxial tests results were used (Fig. 12).

The results can be seen in the Figure 11. One can observe that the yielded areas are all in the time included in the weak zone produced by volumetric deformations due to dilatant behaviour of structured clays.

The above described procedure was used for finding the volumetric strains due to dilatancy distribution during an excavation performance. The results can be seen in the figure no 13. It is important for design to know the slope areas where important deformations process is occuring.

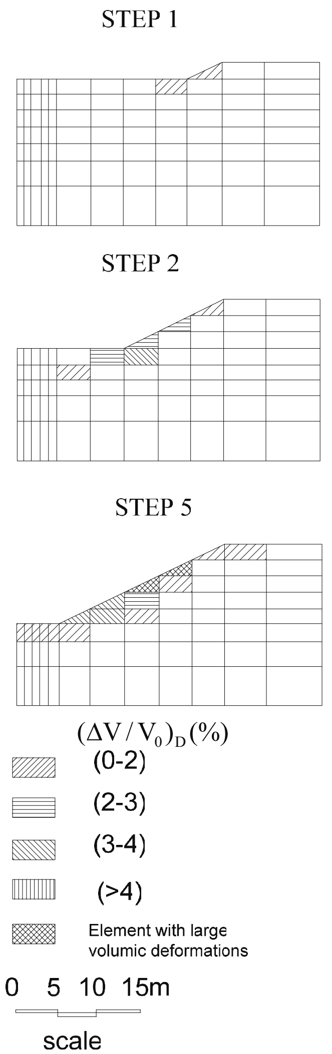


Figure 13. Weakzones distribution during excavation

4 CONCLUSIONS

In the case of the structured clays the shearing displacements lead to relative motions of the structural aggregates still uncrushed, along discontinuity surfaces together with their opening. These relative movements bring about mechanical swelling, and consequently, the increase of water, the shear strength of soil is drastically diminished to the residual value, provoking local failure.

This happens within the Dobrogea and Tulucesti clays, very near the base of the loessian stratum, in which there is free water source. In this way, due to dilatancy a weak zone, right under the loess appeared.

This led to the detachment of a new plot of soil from the plateau, triggering in detrusive way the progressive landslide.

Going further, could be derived that instability phenomena are very likely to occur, when permeable strata lying on structured clay deposits, facilitate the free water access towards mechanically swollen zones due to dilatancy. Consequently, the instability phenomena in fissured clays can be prevented by draining the critical areas or by modifying the soil mechanical properties using chemical and/or thermical methods.

The paper's author consider that, solving the problem starting from the identification of weak zones, using a dilatancy criterion, is more rational than using models with many parameters, usually more than 7, which are hard to determine and without a clear physical meaning.

REFERENCES

Chirica, A. & Stanculescu, I. 1994 Some aspects concerning the macrostructured soils of Romania. Proc. of XIII ICSMFE, New Delhi, vol. I

Chirica, A. 1991. Contributions concerning the influence of cohesive soil macrostructure of settlements and yielding of the foundation ground. Ph.D. Thesis, Technical university of Civil Engineering, Bucharest

Constantinescu, A., Comsa, R., Matei. L. 1979 Analisys of a progressive failure in Panonian clays. Proc. ECSMFE, Brighton

Matei, L. 1983. Panonian clays in Transilvania Romanian Academy Press, Bucharest

Matsuo, S.I. & Kamon, M. 1973. Microscopic research on the consolidated samples of clayey soils. Proc. Int. Symp. "Soil Structures" Gothenburg, Sweden: 194-203

Morgenstern, N. R. & Tchalenko, J. S. 1967. Microstructural observations on shear zones from slips in natural clays. Proceedings of the Geotechnical Conference Oslo: 147-152

Rowe, W. P. 1972 The relevance of soil fabric to site investigation practice. Geotechnique Vol. XXII, No.2

Stanculescu, I., et al., 1995. The influence of structure on the properties of some clay rocks. Proc. XI ECSMF Copenhagen

Stanculescu, I., et al., 1995. Study of the instability phenomena affecting the railway Galati-Barlad. Proc. of the 10th DECSMFE, Mamaia, Romania

Terzaghi, K. 1036. Stability of slopes of natural clays. Proc. 1st ICSMF, Cambridge USA: 161-165

Veder, C. 1981. Landslides and their stabilization, with contributions by R. Hilbert. Springer-Velag, New-York, Wien.