WATER MANAGEMENT DEFICIENCY, TRIGGER OF LANDSLIDES. CASE STUDY BREAZA, ROMANIA.

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1. INTRODUCTION

The site we refer to in this paper is located in the southern part of Eastern (Oriental) Carpathians, in the area of a large synclinorium structure named Breaza-Buciumeni, Prahova District, Romania. The specific type of rocks is marine Neogene deposits, gray and red striped clays, disposed over fissured and faulted limestone or sandstone strata with gypsum, with a total thickness of about 700m. Under the landslide, limestone and sandstone layers are extended in north-east direction with 30º to 50º inclination downward the slope (north-west). Outside the instability area, natural openings reveal that locally, the gypsum layers are dissolved and small to medium karstic apertures creates ways of input of the water into the fissured aquifer located in this structure.
Several years before the accident, the natural valley that may be regarded as a collector basin for superficial rain flow waters has been partially filled up with cohesive materials from excavations and transformed into a plane surface. The uncontrolled operation, wrapped up under 7m to 10m thickness, a permanent spring which continues to discharge underground waters from the neighbour valley, this long-term leakage producing the permanent softening of the lower part of the cohesive fills. As we mentioned before, the trigger factors of the landslide where an increase of moisture in the whole volume of the fills due to a long and hard rain with over average quantities of precipitation, and a seismic event produced in Vrancea seismic area (about 100km north-east) on 27.10.2004 (20.34 U.T.C.) with 6 magnitude (on Richter scale). Eyewitnesses declare that short time before the main instability episode (28.10.2004, 06.30 U.T.C.), some springs appears at the base of the slope followed by strong and deep noises. The first main motion produced, in central parts of the sliding mass, 1m to 5m displacements in about two minutes, with velocities of about 4,2mm/s that include the movement in the domain of rapid-very rapid (Cruden and Varnes, 1996; WP/WLI, 1995). Later on, the slide continues for about six months with a decreasing trend of velocities dictated mainly by precipitations.

2. GEOTECHNICAL CHARACTERIZATION OF SLIDING MASS

In order to obtain the a complete description of the unstable mass and of the main causes, two types of field investigations has been performed: six geotechnical boreholes at maximum 10m depth for physical characterization of the sliding mass based on 50 samples and over 60 geoelectrical soundings at depths between 20m and 45m, for deep geometric characterization.

On samples collected from boreholes, some basic geotechnical analyses have been executed, in order to define the terrains affected by instability. Results revealed that the grain size distribution, according to Unified Soil Classification System (ASTM D 2487 – 06), is composed mainly of inorganic fat clay CH (86%), fat clay with sand (11%) or sandy fat clay (3%), with high plasticity and also established the limits of the fundamental indexes. Undisturbed samples of clays tested in direct shear mode (unconsolidated-undrained) put in evidence values for direct shear parameters, in ranges of 16^o-20^o for friction angle, respectively 23-35KPa for cohesion, which was found in agreement with results of triaxial compression ($\phi=21^o$, c=42KPa; $\phi'=25^o$, c'=57KPa). Remoulded samples of fat clays from sliding mass has been tested at moistures between 18-55%, in direct shear apparatus. Results are presented as the variation of shear parameters with moisture, in fig.1 bellow. The fitting curves obtained for $c=f(w)$ and $\phi=f(w)$ dependencies are exponential and polynomial with notable correlation coefficients 0,98-0,99. Saturated hydraulic conductivity of sliding soils was tested by three types of tests: by falling head permeameter ($2\div3\cdot10^{-4}$ cm/s), by the constant head in the triaxial cell ($4\cdot10^{-7}\div5\cdot10^{-6}$cm/s) and indirectly obtained from consolidation tests in odometer ($2\cdot10^{-5}\div8\cdot10^{-4}$ cm/s). Stable soils represented by fat clays has been also tested and average values was found in contrast with the previous results of sliding mass soils: γ = 20,4KN/m^3; γ_d=15,9KN/m^3; n=40%; Sr=0,55; $\phi=28^o$, c=80KPa (direct shear, UU); k=$3\cdot10^{-6}$cm/s (falling head method).

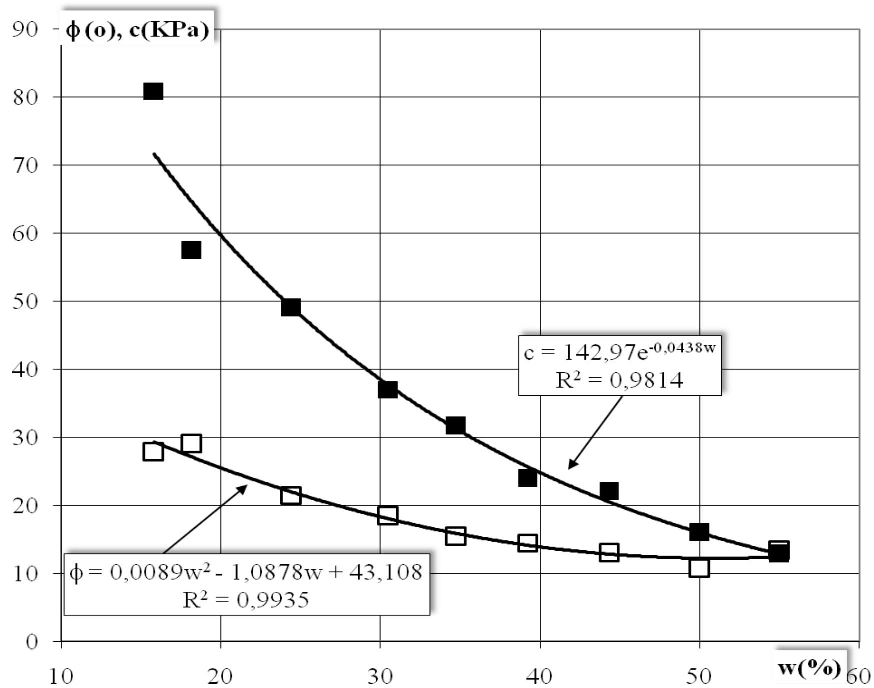

Fig.1. Variation of direct shear parameters with moisture

3. SLOPE STABILITY ANALYSES

Slope stability analyses were executed using an automatic programme based on Janbu theory (Janbu, 1954) for four sliding surfaces. The geometry of sliding surfaces specified by geophysical surveys together with main properties of interslice forces. Each surface was analysed in various conditions of shear resistance dictated by moisture content, in the limits of parameters described in previous section. Results consist in ranges of decreasing factors of safety with increasing moisture, corresponding to each sliding surface and are presented in table 1. Also, for every specified sliding surface, a representative trend equation has been established for the factor of safety versus moisture content. These equations allows defining the critical moisture of each surface as the moisture which induces through associated shear parameters, the limit equilibrium of the sliding mass ($F_s=1$). For all the four sliding surfaces, the trend equations are presented in figure 2.

Table 1. Slope stability analyses results.

Average moisture	*w (%)*	*24*	*31*	*35*	*39*	*44*	*50*	*55*	w_{cr} ($F_s=1$)
Factor of safety F_s	*S1*	*3,66*	*2,84*	*2,39*	*1,95*	*1,79*	*1,40*	*1,14*	*57*
	S2	-	*2,21*	*1,87*	*1,55*	*1,43*	*1,13*	*0,92*	*53*
	S3	-	-	-	*1,53*	*1,42*	*1,12*	*0,91*	*53*
	S4	-	*2,44*	*2,06*	*1,70*	*1,57*	*1,24*	*1,01*	*55*

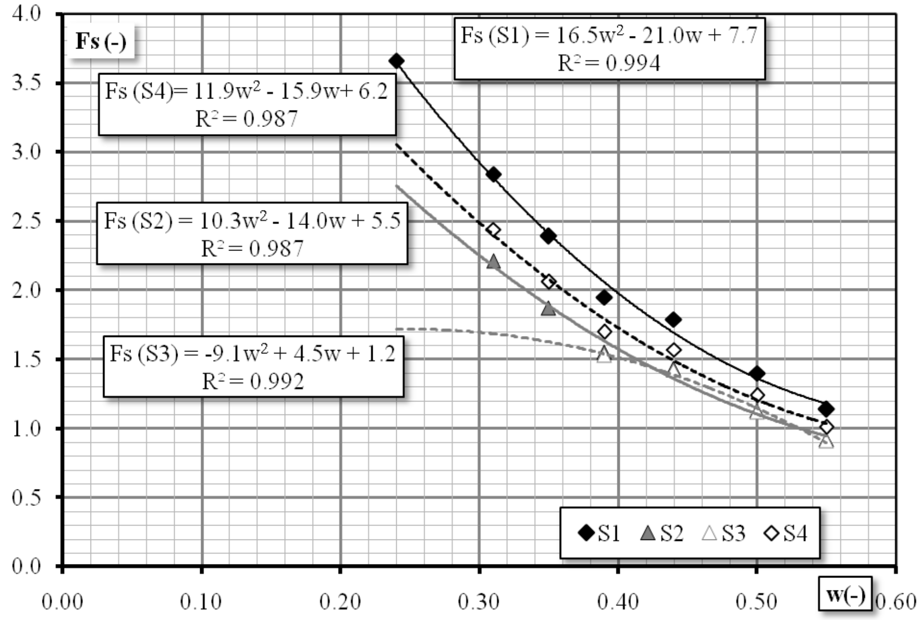

Fig.2. Variation of the stability factor with increasing moisture

4. REMEDIAL MEASURES

Corroboration of all investigation and calculation results, conduct to the conclusion that the only rational and economical remediation measure is a superficial drainage system, positioned outside and over the whole slide, in order to prevent infiltration of rainwater and superficial flows into the sliding mass.The design of the drainage system tooked into consideration the surface of retention basin that overlap with slope slide (31600m^2), the specific debit of maximum precipitations in 24h (q_{24}=1330 l/s·km^2), the average specific debit of superficial flow of rain waters (q_{sup}=5÷10 l/s km^2). The resulting network consists of three branches of superficial, hydro isolated drains, accounting 1300m, with trapezoid section of 0,50m depth, slopes between 10^o and 20^o for which the estimated collected debits (q_{max}=60-70 l/s) will be discharged outside the area of instability.

5. CONCLUSIONS

1. The high degree of saturation of soils revealed by geotechnical tests and confirmed for the whole sliding mass by geoelectrical surveys certify a slow but continuous infiltration-absorption process of waters in deep down from an ancient spring (covered by fills) and on the surface from rain water flow favoured by the geomorphologic shape of the valley. The main and tremendous consequences of this facts are the increasing pore pressure and decreasing of shear parameters of soils with increasing moisture.

2. Regarding the tight intercourse between moisture content and shear parameters, we established for this particular case, (on remoulded samples of fat clays from sliding mass), laws of variation $c=f(w)$ and $\phi=f(w)$ with notable correlation coefficients.

3. In the next step, we have tested the state of equilibrium of the slope, with Janbu 's theory calculations for few complex slide surfaces and at different shear parameters corresponding to the range of increasing moistures. Results allows us to established some reliance specific only to those soils and those geometric slide surfaces:

- moistures over 45%, induces alarming values of safety factors under 1,3;
- moistures over 50%, induces small, local sliding on superficial slip planes;
- moisture content over 53-57%, may produce a large or even an overall sliding on the deepest shear plane (about 15m depth) because the range of critical moistures ($F_s=1$) of tested sliding surfaces extends between these limits.

4. The drainage system was executed in one year after the main instability event (2005). Since then, it has been permanently corrected following the shape of the slope surface with a decreasing trend of displacements.

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