LANDSLIDES ANALYSIS USING GEOLOGICAL, GEOTECHNICAL AND GEOPHYSICAL DATA FROM EXPERIMENTAL MEASUREMENTS IN PRAHOVA COUNTY

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Abstract. The landslide that is the subject of this paper occurred in Prahova County. The present work was carried out to study the spatial influence of geological and morphological factors upon landslide occurrence on a local scale by using geotechnical and geophysical methods in order to determine local trigger parameters. The input data for the slope-stability analysis were collected from topographic investigations, geological mapping. In addition, soil geotechnical parameters were collated from a series of in situ tests. A geophysical survey was applied by using vertical electrical soundings in order to detect the existence and continuity of a potential sliding surface.

Key words: behavior, landslide, risk assessment, site characterization

1. Introduction

Landslides are widespread in many hilly regions of Romania, particularly those underlain by flysch deposits, which are complexes of folded and faulted sedimentary rocks containing marls, days, sandstones, and conglomerates. The analyzed area is situated, from morphological point of view, in the Curvature Subcarpathians in Romania, built of Cretaceous-Paleogene flysch and Mio-Pliocene molasse deposits, an area affected by a large diversity of mass movements.

Especially the Curvature Subcarpathians have very high landslide-occurrence potential, due to such characteristics as structure, lithology, morphometry, land-use and land-cover changes as a result of intense human intervention and heavy rainfalls. In terms of geomorphology, slipped areas are on land with slopes of 15 to 24 degrees. From the hydrological point of view, the area is tributary of the Prahova River whose course is located 1 km from the investigated area.

According to the macrozonation mapping of landslides in Romania, the studied area is located on land with potential medium and medium probability of sliding.

The complexity and the major importance of landslide hazard for the geotechnical engineering research requires a careful site characterization, „in situ” and laboratory investigations due to the different responses of the terrain according to the geological, physical, hydro-geological and soil mechanical characteristics, morphological and anthropogenic conditions, which control the surface and subsurface water flow and hence, the instability of the slope (Terlien 1998).

During 1997 heavy rains was produced a regressive type of slope instability, which moved the entire road platform for a length of 30 meters. As a result of the soil massive displacement, a rupture of the ditch drainage water systems on the right side of the road occurred, which led to groundwater rising in the landslide mass and increasing the slope instability. The affected area was consolidated in 1998 and consisted of ten strengthening pieces execution from two 1.08 m diameter piles at the existent retaining walls. The pilots were designed at 12 or 15 meters depending on the location. The strengthening pieces founded on Benoto piles are located at an inter-distance of 5 meters.
The instability phenomenon was reactivated in 2006 due to intense rainfall. The main cause of triggering landslide is the pluvial drainage system malfunction, which allowed rainwater to infiltrate into the landslide mass and to create preferential paths in the county road embankment, forming a separation line. In the same year, it was drawn up a technical paper to evaluate the existing situation of the area and recommendations and technical measures were issued in order to minimize the loose slope stability effects, but were not respected.

In March 2010, the situation of extreme degradation of Prahova County road has been generated by geo-mechanical natural causes and by the infringement of technical recommendations provided by technical expertise performed in 2006. From 2006 to 2010, after four years of repeated freeze-defrost cycles, as a result of heavy rainfall, the old landslide event was reactivated due to various causes. The entire consolidation area, in the road curve, including the retaining walls located above the solidarity beams of columns and columns themselves, could not be inspected over their entire length, noting that the charge in the slope active area is not suitable for helping to reactivate the landslide mass.

The retaining walls have non operational drainage systems and require to be put into function since the elimination of water resulting from infiltration is stored behind the walls.
The drains, which are designed to collect surface waters and to direct them to a discharge point, do not allow collection and disposal of surface water due to the high flow which has to be evacuated after torrential rainfall.

The settlement of county road with 30-40 centimeters on 60 meters portion was mentioned (Fig. 1), with obvious longitudinal and transverse cracks in asphalt pavement because the foundation gave up due to lateral repression of the form strata and natural ground on which it is located; the road settlement caused damage to houses and traffic restrictions.

Due to the changing of humidity conditions, the landslide occurred concomitantly with increased erosion to the slope. At the landslide reactivation contribute the loading of the slope because at the top part are stored domestic waste deposits and construction elements (Fig. 2) and caused the growth of shear stresses within a slope.

The main objective of this study was to investigate the instability mechanisms behind the rainfall-triggered landslides, which occurred in January 2010, in the Prahova County and caused considerable damage to road and houses. The intense rainfall event caused a near-immediate response in the form of a landslide by rapidly increasing the stresses or strains and reducing the strength of the slope-forming materials (Wieczorek 1996).

2. Theory and Method

Following the basically recommendations described in the recent technical expertise, the specialists were elaborating a research program based on the assessment of local soil conditions.

The survey investigations performed in the landslide area consists in topographic measurements, geotechnical boreholes, geological mapping and geophysical measurements. The topographical measurements were performed in order to outline the longitudinal and transversal profiles of the slope by using local station, in STEREO 70 coordinate system. The topographical profiles are illustrating the difference in level to be enhanced and the gradient of county roads that require immediate interventions.

The geotechnical investigations consists in performing mechanical boreholes, with continuous coring, up to 20 metres depth in order to establish the lithological sequence of the site and to gather soil samples. The borehole was performed in the curve of the county road, in the landslide triggering area. The laboratory tests were performed for the determination of physical parameters, deformation and strength parameters.

The soil profile obtained up to a depth of 20 meters indicates clayey soils and marly clay with rare intercalations of silty and sandy layers, limestone lenses. The carried out laboratory tests on the soil samples consists in: physical characteristics (grain size analysis, moisture content, unit weight and density, porosity, pore index, Atteberg limits), and deformation and shear strength parameters.

The landslide mapping allows the linkages that this phenomenon has with bedrock petrography, geological structure, age deposits and tectonic region. Based on geological mapping, prospecting works and existing technical papers will be prepare a geological and structural section, which represents the contact between deluvial deposits and the bedrock, the limits of geological formations between formations, the location of major structural elements (faults, folds axes). The area where the landslide occurred is part of the Carpathian flysch, called “Bobu Unit”. In the landslide area which affects the county road appears flysch ensemble consists of marls and sandstones, with strong deformations and chaotic arrangement (Fig. 3).

During the landslide, portions of the flysch formations were moved gravitationally and deformed. Based on field observations, it can be considered that the last landslide resumed and older landslides occurred in the same area. It was difficult to measure the direction and inclination of strata in the landslide area and they have tilts about 45-50 degrees to the south, with many variations due to intense tectonic events, which favours production of deluvial deposit slip at the contact with them and even some portions of the bedrock along the bedding planes.

The fractures are oriented NW-SE, respectively NE-SW, leading to an area subdivision in numerous lowered or raised tectonic blocks, where the geological formations consists in marls and sandstones with different ages come in tectonic contact. In the investigated area, beyond flysch ensemble, considered as the bedrock of the landslide, there are quaternary gravels, suspended terrace deposits related Riss glacial period. Frequently, at the contact between gravel deposits and flysch formations, groundwater springs are formed, with major role in causing sliding of quaternary deposits over the bedrock.

The geophysical investigations carried out allowed us to characterize precisely the morphology of the base landslide and provide a good estimation of the moving mass. The geophysical prospecting is based on techniques used in the research on landslide hazard. The method applied was vertical electrical sounding (VES) and will get information on: the boundaries between rock formations and deluvial deposits, the degree of fissuring of the rocks, the thickness of sliding layer, the thickness of aquifer strata, flow directions and water velocities, moisture content of the rock and humidity variation in sliding mass. The geophysical prospecting will accompany and complement the geotechnical investigations.

3. Results

The analysis regarding the stratification of the soil, based on laboratory tests, has the following results:

- layer 1: top soil, backfill consists of gravel and ballast up to 1.20m depth;
- layer 2: clayey deposits consists in silty clay up to a 6 meters;
- layer 3: clayey deposits consists in sandy clay with rarely crushed stones up to 12 meters;
- layer 4: marly deposits consists of grey marly clay, with breccias issue and sandstone elements, strongly affected by tectonic events, up to 20 meters (Superior Aptian geological stage)

Based on the laboratory tests the following physical soil characteristics were determined: grain size analysis, moisture content, unit weight and density, porosity, pore index, Atteberg limits. Regarding the grain size analysis, the analyzed soil samples are included in the clay soil category, represented by silty clay and sandy clay, as shows in the ternary diagram from Fig. 4.

The Atterberg limits are a set of index tests performed on fine grained silt/clay soils to determine the relative activity of the soils and their relationship to moisture content. The analyzed soil samples are characterized by a plasticity index ranging from 23, 22 % up to 51, 52 %, soils that fit in the high and very high plasticity categories, and consistency index ranging from 0,910 up to 0,986, soils that fit in the stiff category.

Regarding the mechanical laboratory tests, the soil compressibility caused by external loads is expressed in terms of oedometric deformation and specific settlement. The tested samples are included in the soil categories with high and very compressibility. The obtained data indicated that recently, the landslides are occurring in very highly compressible soils, under external loads (heavy traffic, upgraded transportation routes, various types of constructions.

Based on the quantitative interpretation of the vertical electrical sounding curves, by using automatic calculation software, there were built geoelectrical sections, which show the vertical distribution of apparent resistivity values. The analysis of geoelectrical sections in parallel vertical resistivity sections indicated the existence of two geoelectrical limits, which are delimited the following layers:

- layer 1, with a thickness of 1,5 meters, consists of top soil and filling material (VES1, VES2), characterized by values of resistivity layer in a wide range, ρ_S= 23-340 Ωm;
- layer 2, intercepted from 2,2 meters up 6,7 meters depth, consists of marly clay, intensely altered and characterized by a mean resistivity value of $\rho_S \approx 32.4$ Ωm;
- layer 3, consists of marl deposits, with breccia and sandstone elements, characterized by lower resistivity values, $\rho_S \approx 14$ Ωm. Locally, in case of VES2 and VES6, there were high levels of resistance that characterizes the deformed lenses or layers of sandstone or marly limestone.

It is mentioned that the sliding surfaces are located up to the contact between layer 2 and 3, and the sliding material can be found in layer 2. On the basis of geoelectrical data, combined with geological mapping data was prepared a representative geological section for the county road platform (Fig. 5).

The establishment of the sliding surface in the area by using various methodologies for an extensive investigation of the landslide area will conduct to several technical solutions, which will reduce the site vulnerability to landslide hazard, including the effects on people and structures. In general, to predict landslides, one must assume that their occurrence is determined by certain geologic factors, and that future landslides will occur under the same conditions as past events (Lee and Talib 2005).

The technical project carried out in the affected landslide area provides the technical and economical details for the stability and rehabilitation of the county road located in landslide triggering and sets the consolidation solutions and directing surface water away from the landslide mass.

The technical works for the local consolidation consists in the following operations:

- the slope cleaning works (removal of domestic waste deposits) and also edge of the road platform;
- the rehabilitation of the road platform: the slopes and overall dimensions remain existing road platform; the geomorphologic conditions, it is not possible to restoration the slope to the curve;
- at the road platform edge is required to perform a series of drilled micro piles on a row, with specific drilling diameter and inter-axial distance;
- the restoration of the drain situated between the road and the road platform on o considerable distance;
- the removal of the domestic waste deposits from the concrete drain and local repair where the concrete is deteriorated or is missing;

- on the houses side, there is a rectangular concrete drain, which is blocked and locally degraded; removal works and reparations in the damaged areas are required;
- the execution of two roadway drains, across the road; in the upper part of the road is required a drain in order to collect pluvial water before draining the curve road;
- the execution of a deformable parapet on the roadside to the valley;
- the execution of drains on the slope.

4. Final remarks

This study, carried out in one of Romania's most landslide-affected areas, reveals the importance of landslide hazard assessment, given the strong and long-term influence of landslides on settlement development and optimum land use. The emergency management on the area affected by landslides using geological, geotechnical and geophysical analysis based on experimental measurements is developed in order to establish the most feasible technical and economical solution for people and structure safety.

The emergency management consists in the following main activities:

- warning signs panels regarding the existence of an area affected by landslides;
- people's education concerning ensuring the stability of the area by respecting the demands regarding the deployment of the waste deposits in special designated areas;
- participation of the local authorities by providing resources for monitoring the area in rainy seasons;
- people's education and local authorities involving in stopping deforestation and halt the expansion of the residential area in the local area or in other areas having similar local conditions, without the elaboration of complex and extensive geotechnical reports and large scale slope protection works (drainage water systems, stabilizing slopes, drains, etc.).

REFERENCES

Chițu Z., Sandric I., Mihai B., Săvulescu I., (2009), *Evaluate Landslide Susceptibility using Statistical Multivariate Methods: A case-study in the Prahova Subcarpathians, Romania*, Conference Landslide processes. From geomorphological mapping to dynamic modelling, Editions du CERG, Strasbourg, pp 265-270.

Jelínek R., Hervás J., Wood M., (2007), *Risk Mapping of Landslides in New Member States*, EUR 22950 EN – Joint Research Centre – Institute for the Protection and Security of the Citizen, 34 pp, ISSN 1018-5593.

Lee S., Talib J. A., (2005), *Probabilistic landslide susceptibility and factor effect analysis*, Environmental Geology 47: 982.

Murarescu O. M., Pehoiu G., (2010), *Environmental impact of landslides in sub-Carpathian area between the valleys of the rivers Dâmbovița and Prahova (Romania)*, WSEAS TRANSACTIONS on Environment and Development 2(6):73-82

Terlien M. T. J. (1998), *The determination of statistical and deterministic hydrological landslide-triggering thresholds*, Environmental Geology 35 (2-3):124-130.

Wieczorek (1996), *Landslide triggering mechanisms.* In: Turner, Shuster (eds) *Landslides: Investigation and Mitigation*, Transportation Research Board-National Research Council, Special Report, vol. 247, pp 76-90.

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Fig. 1. The settlement of county road, cracks in the asphalt pavement

Fig. 2. The loading slope due to household deposits and construction elements

Fig. 3. Marly deposits affected by tectonic events

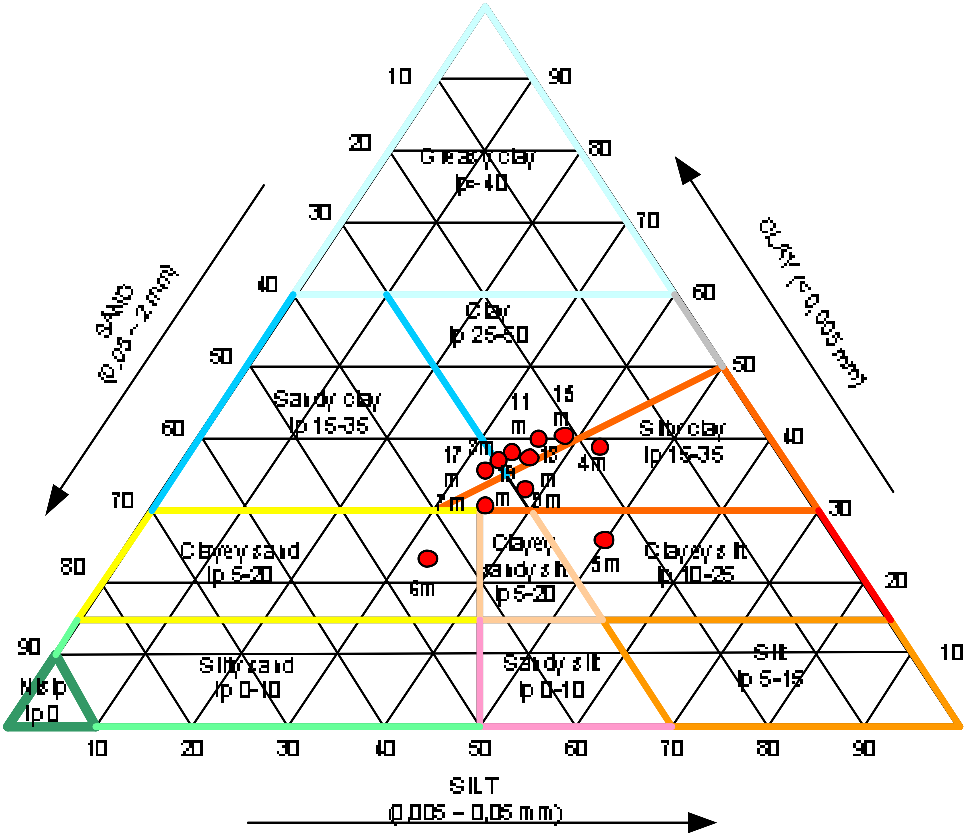

Fig. 4. The soil classification in the ternary diagram

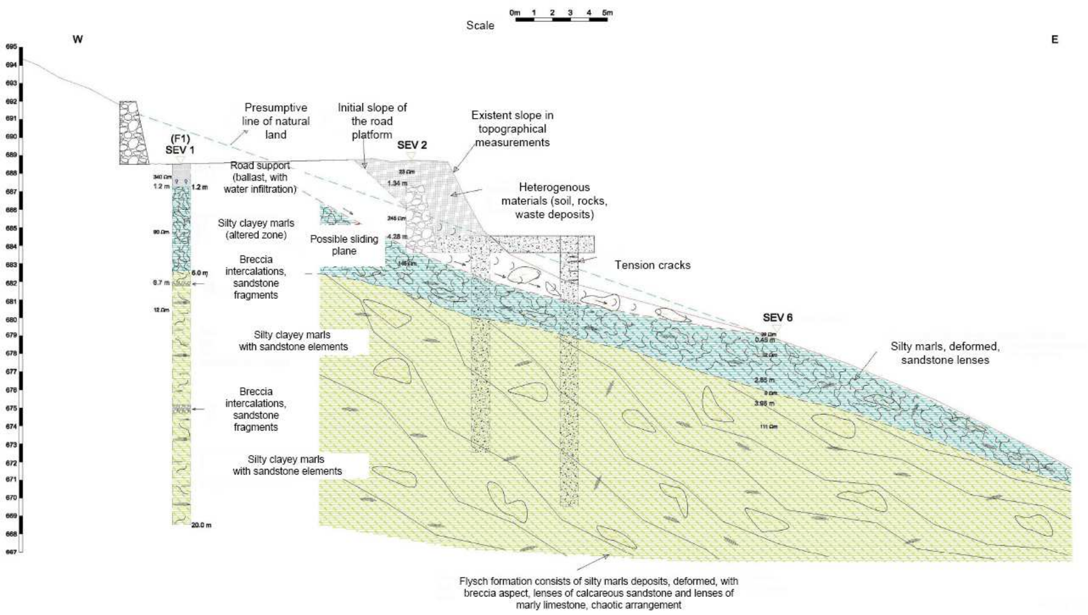

Fig. 5. Geological cross section in the county road platform