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EXPERIENCES WITH MONITORING OF LANDSLIDE IN SOFIA'S SUBURBS OF FILIPOVTSY

Introduction

The present work describes public and technical activities related with the activation of a landslide in the Kutlina locality of the Filipovtsi suburb, situated in the western outskirts of the Sofia City. Landslide phenomena are manifested also in many other settlements in Bulgaria and very often, as in this particular case, they drastically change the daily life of citizens whose real estates have been affected by the disaster. In this way the hazardous geological natural settings provoke the public and administrative awareness for a more effective solution of geotechnical problems.

Prehistory

Visual construction damages appeared on a number of residential buildings (observed since May, 2004), and in a section of the Poruchik Hranov Street the roadbed collapsed and the traffic along it was stopped. The survey of the specialists established widening of the zone affected by landslide activity with a real threat for the nearby situated kindergarten for about 50 children. An Initiative Civil Committee was founded (2002) that started lobbying together with the municipal authorities for the allocation of resources from the Republican budget, Investment program direction – Project "Bulgaria – II stage". An Expert technical-economic council (ETEC) was established and the provided resources were used to assign the feasibility studies "Engineering geological and hydrological investigation". Attempts for further financing from the European Investment Bank were made.

Engineering activity

In conformity with the existing requirements for public commissioning assignment, contractor companies were appointed to carry out terrain explorations and to select technical solutions – design and stages of execution.
Geodetic survey was conducted for the affected terrain, followed by engineering geological and hydrogeological exploration in accordance with the normative requirements for geoprotective measures on the territory of the country.
On the basis of the enumerated activities the ETEC proposed the following possibilities for solving the problem.

First stage
- Surface drainage using ditches of precast reinforced concrete elements;
- Lowering the groundwater level by means of draining ribs and horizontal drainage walls;
- Vertical planning of the terrain;
- Installing a system for monitoring and long-term observations.

With the productive cooperation between the Metropolitan municipality (assigner in this case), the Initiative Civil Committee, ETEC, the Construction Supervision and the Companies Designers & Constructors, the First stage was successfully completed in 2007.

The observations in the course of one year, carried out using the monitoring system, and the analyses of ETEC proved the necessity of the *Second stage* – strengthening in order to prevent activation of the terrain in the upper part of the landslide massif. Two variants were developed – with an "armored concrete bearing wall" (Variant I) and "cast piles – braced beams – concrete retention wall (Variant II). The Second Variant was selected for design and the developed project was approved. The Metropolitan municipality submitted application for this project in the "Regional Development 2007-2013" Operative Program, priority line 1 – "Sustainable and Integrated Urban Development".

Location and Hydrogeological Settings

The landslide terrain is situated in the northwest part of the Sofia City, the Filipovtsi quarter, to the north of the "Vasil Levski" St. It is spread on a slope with north-northwest exposition at an altitude of 565-595 m. The boundary of its lower part is the Banska River. The maximum slope inclination is 22-25^0.

It is rather unfavorable for the status of the landslide terrain that there is no wastewater sewage system in the region. In this way surface and waste water is drained directly in the earth massif.

According to the performed terrain and laboratory investigations and analyses the geological structure is characterized by the presence of Quaternary and Neogene systems. The following typical stratification is outlined. *Layer 1* (depth, 1.7÷3.8 m): silty to silty-sandy clay of brown/black-brown color. *Layer 2* (1.2÷4.2 m): clay, silty-sandy with brown/red-brown color, with clayey sand intercalations at some places. *Layer 3* (3÷5 m): dense silty to sandy red-brown/gray-black clay. *Layer 4* (2÷2.8): sand, varigrained, to silty-clayey with sandy clay intercalations at some places. *Layer 5* (2.8÷9.8 m): dense clay, silty to silty-sandy, light brown to gray-brown.

The groundwater is drained along the sandy-clayey intercalations and lenses, and is accumulated in the impervious clay layers. The natural runoff of surface water in the region, and mostly household wastewater, flow freely into the landslide massif and are the principal reason for the manifested surface movements.

Construction solutions for terrain stabilization

These solutions are based on the detailed geodetic survey of the terrain and on the developed digital model for it. In this way the design of all anti-landslide structures is facilitated and optimized to the maximum extent. The tracing of the structures is conducted from stabilized reference points with coordinates established by GPS measurements.

The built anti-landslide facilities during the *First stage* possess the following construction features.

<u>Surface open drainage ditches</u>

- *Ditch No 1*: starts from the highest part of the landslide massif; length of 353 m; mouths the Banska River. It drains the formed boggy area at the top part of the landslide. In this way, except for the purely geotechnical, a sanitary problem is also solved in the region.
- *Ditch No 2*: collects the surface water under Ditch No 1; length of 113.5 m; discharged (in the same ditch No 1);
- *Ditch No 3*: is situated in the lower most part of the terrain; discharged in Ditch No 1; 156 m long.

The depth and width of the ditches is 0.4 m and their wall thickness is 0.15 m.

<u>Draining ribs and revision shafts</u>

Five draining ribs (depth 1.3÷4 m and length 88÷187 m) were built from crushed stone. Revision shafts are envisaged in the places of discharge of the draining ribs.

<u>Horizontal drainage boreholes</u>

Three horizontal boreholes were drilled with a length of 100 m each and a diameter Ø146 mm. The boreholes begin in the landslide's toe and are situated in a fan-like pattern at angle of 30^0 between their axes. They mouth in the revision shafts of the discharge channel.

<u>Discharge collecting channel</u>

This channel collects the water from the above facilities. It is 171.6 m long and its diameter is Ø315 mm.

Monitoring system

The monitoring system was designed and realized on the basis of the hydrogeological and geotechnical explorations in coordination with the authors of the work project for landslide stabilization. On the grounds of the landslide geometry, the previous geodetic measurements and the project budget, key observation parameters have been selected, providing direct information about the development of probable landslide phenomena. These parameters are pore pressure, groundwater dynamics, in-depth and surface deformations.

Standpipe piezometers

Five piezometers are built with a depth of 10 m. They are situated in specific places and are used for recording the effect of the drainage facilities and the influence of the infiltrated surface/waste water in the massif. The measurements are performed using an electric sound and a cable band with a millimeter scale. When the sound contacts the water in the piezometric pipe (Ø32 mm), an acoustic signal is heard at the surface. In this way, the water level is determined in the course of time – the pore pressure and the hydraulic gradients.

Inclinometric casings

They serve for the monitoring of in-depth horizontal displacements – localization of probable shear planes. Two casings are installed: IC01 (Inclinometer Casing No1) with a depth of 14 m, situated in the upper front part of the landslide, and IC02 with a depth of 11.5 m, situated in the upper central part.
The inclinometric casings are monolithically fixed in borehole plastic pipes (ABS) with an external diameter Ø87 mm and have peripheral axial channels at each 90^0. In fact they fix definitely the base of the inclinometric sound for the in-depth measurements (starting from the bottom – at every 0.5 m).
The sound at the surface is connected with a GK-603 Readout Box (www.geokon.com). The Readout Box stores and automatically processes the measurements in order to obtain information for the in-depth and total displacements (for a current observation after an initial one).

Geodetic network

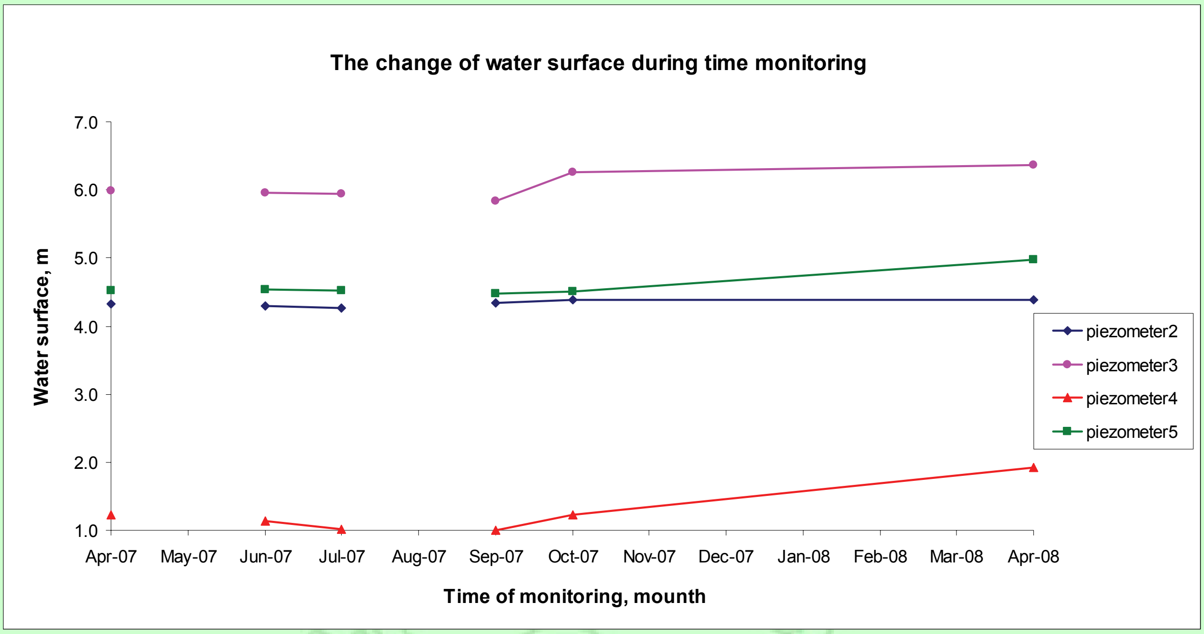
The geodetic observations help to understand the range of the surface movements, as well as their direction and average velocity. The network is built in a local coordinate system and includes: four reference leveling benchmarks beyond the area of the landslide and 25 surface benchmarks inside it. The measurements are carried out with a total station WILD1610 and a prism 17.5 with a mini stock and a tripod for centering.
Instructions for operation maintenance have been prepared for the appropriate long-term exploitation of the system.

Results from the observations

Within the one-year period after the Monitoring System construction five current measurements were carried out in the standpipe piezometers and in the inclinometric casings, as well as two geodetic measurements of the surface benchmarks. The measurements were carried out during different seasons in order to record the influence of the climatic factors – mainly precipitation.

Piezometric measurements

As a whole, no significant change is observed in the piezometer water level (attached diagram of water surface/time of monitoring) – obviously the drainage facilities are effective.



Inclinometric measurements

The analysis of the total deviation graphs (ΣDA) along the supposed direction of displacement does not reveal in-depth displacement exceeding the range of the total system accuracy (±6 mm per 25 m). Practically no displacements are recorded in the lower most part of the columns, 3 m from the bottom, i.e. they are in immovable materials. This is an indication for appropriate installation and a prerequisite for reliable future interpretation of the long-term observations.

Geodetic measurements

The results from the two current observations are given in two maps (not applied due to the limited volume of this work): *the first* one shows the situation plan of the area of the landslide with the direction and magnitude of displacements for each surface benchmark, and *the second* one shows the vertical deformations – settlement/swelling, obtained for each benchmark during the conducted precise leveling.

The most substantial surface deformations are established for the control benchmarks No 11 – 45.5 mm (upper central part of the landslide), and No 9 – 25.2 mm (upper central-west part of the landslide). Settlement of 63.2 mm is observed for control benchmark No 4 (upper middle-east part) and 45.3 mm for benchmark No 13 (upper, front-east part).

Visual observations

The visual observations contribute to complement and summarize the instrumental observations. The status of the permanent objects on the terrain as protected inlets of the piezometers and inclinometric casings, buildings, columns, etc., may provide evidence of slope creep – especially after heavy precipitation.

Conclusion

The applied approach to the stabilization and observation of the landslide phenomena in an urbanized region as the "Filipovtsi" quarter is instructive in confirming the necessity of the joint efforts of the citizens, local administration and the geotechnical college. Moreover, in this way a more careful attitude is cultivated to the natural settings and built engineering structures with the view of preserving and complementing them in the future.