Professional paper
UDC: 624.131.537:550.82(497.6)
DOI: 10.7251/afts.2016.0815.001D
COBISS.RS-ID 6174488

GEOTECHNICAL CHARACTERISTICS OF TERRAIN AND PROPOSAL FOR SANATION MEASURES OF LANDSLIDES SULJENDICI, MUNICIPALITY SREBRENIK

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ABSTRACT

Period of intense rainfall during May 2014 was characterized with the occurrence of a large number of landslides on terrains that have not been previously threatened by human activities, and also terrains that were the subject of engineering activities. To separate terrains that are not threatened by human activities is difficult. Still they can be observed as the terrains where in general there is no presence of human interests and terrains where people live and bring slopes to their own purposes, but do not impair the nature by doing certain technical procedures.

Seen as a whole, the most vulnerable are hilly and mountainous terrains, which mainly represent conditionally stable slopes. Some of them are abandoned and some are brought to human purposes. Both are usually conditionally stable, only is difficult to determine where is easier to distort the natural stability. At the top of the slope are mostly smaller settlements, which partially maintain slopes in their conditional stability, but also sometimes disturb that stability.

Great rainfall in May 2014 have left the greatest consequences on such terrains. Majevica, as a mountain known for such slopes on its peripheral parts, only demonstrated earlier prediction that on its terrains can frequently occur landslides, which requires a more detailed study of the terrain if used for certain purposes, especially in the construction of individual residential objects.

Landslide Suljendic is located in the Srebrenik municipality, which is characterized by terrains where occurred the largest number of landslides. More detailed landslide is on the slope that from three sides surrounds several individual objects, built on its top. For years, the slope held its conditional stability, however during the mentioned period on each side started a movment of the rock mass which formed three landslides independent of each other. On the north side is the relevant landslide for which were carried out terrain and laboratory tests and was given sanation proposal.

Key words: *slope, landslide, geotechnical characteristics of the terrain, sanation*

INTRODUCTION

Landslide in village Suljendici, municipality Srebrenik, is studied within the Development Program UNDP BiH, as one of priority that needs to be repaired. It is located on the north hillsides of mountin Majevica, on a slope that is conditionaly stable. On top of the slope is a small populated settlement, ie several individual residential objects with additional objects of other purpose. Since the slope surrounds populated settlement, its been cultivated by local residents for years, and kept its conditional stability. Over time, the slope was less cultivated, and individual facilities become more modern. During the time of cultivation of slope, surface waters were orderly taken through small channels in hypsometrically lower parts of the terrain to the local stream.

With cessation or lessening of cultivation of the slope, on the same, during the summer appear large cracks that later in rainy period, collect water, whereby the structure of sediments and their conditional equilibrium state are disturbed. If we have in mind that the individual objects were modernized and that they drained water uncontrollably towards the slope, then it was created a lot of conditions for the distortion of its stability. However, slopes maintained its conditional stability until May 2014, ie several days of intense rainfall, and then from their three sides occurred launching of the surface part the rock mass, forming landslides independent of each other. Investigated landslide besides endangering individual objects on top of the slope, also endangers local stream located at its bottom.

Conducted terrain research and laboratory tests gave enough results to elaborate the project of slope sanation, and the local stream, from whose left side is the cemetery.Stream arrangement will prevent undermining the slope stability towards the cemetery.

CHARACTERISTICS OF THE TERRAIN AND LANDSLIDE

The terrain, in the broader sense, is studied during the development of Main Geological Map, sheet Tuzla, in the scale 1:100000, [1,2]. More detailed studies have not been carried out even though in all surrounding slopes were built many individual objects. According to the size and significance of landslides, research works were carried out in the form of boreholes and trenches, but under their completion in individual boreholes are installed observation piezometers and inclinometers [3,4], figure 1.

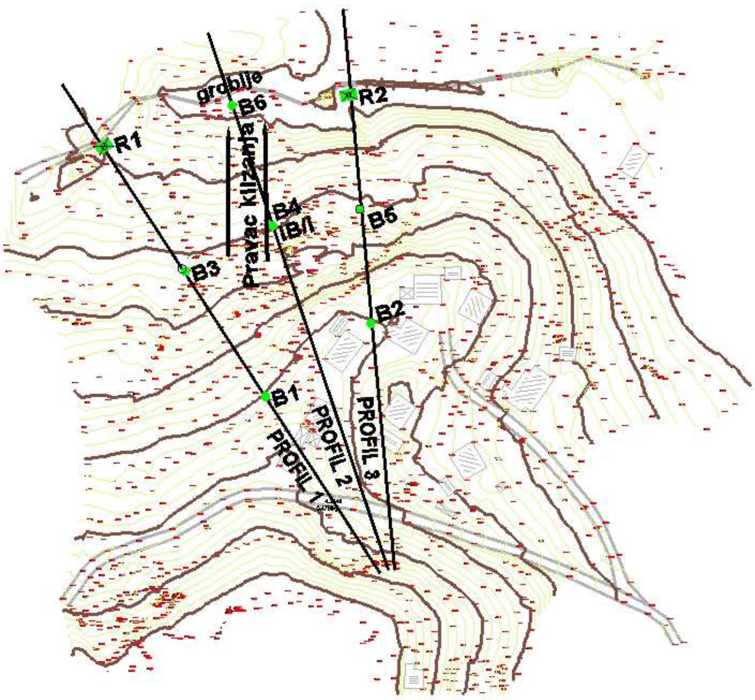

Figure 1. Situation map with an overview of research works

Precursor to research works are detailed engineering geological surveys of the slope and wider surroundings [3,5,6,7]. Special attention is paid to demages of residential objects and access roads, but also to recording of characteristics of landslide, where is sufficiently defined:

- lithological composition of the terrain
- spreading and characteristics of frontal scar and secondary scars of active sliding as well as protrusions and sags on the body of landslides which are characteristic for active landslide
- increased humidity of terrain and directions of water filtration
- demaging of residential and additional objects
- characteristics of local stream which is located at the bottom of the slope
- other occurrences that can have importance for development of project documentation, sanation and impact on performance of sanation procedures

The area of landslide is build of clay sediments which observed in the vertical profile can be classified as colluvial diluvial sediments, leyer 1, below which are reddish sandy silty clays with tiny fragments of rocks, leyer 2, figure 2. Below these lie tuffites clays, leyer 3, which are often interleyered with reddish and misty gray clays. Substrate of the terrain consists of degraded sandstones and conglomerates and clayey gravels and sands, leyer 4. As part of the substrate at the bottom of landslide are allocated in the form of lenses, plastic sandy clays with fragments of rocks and gravel pebbles [4].

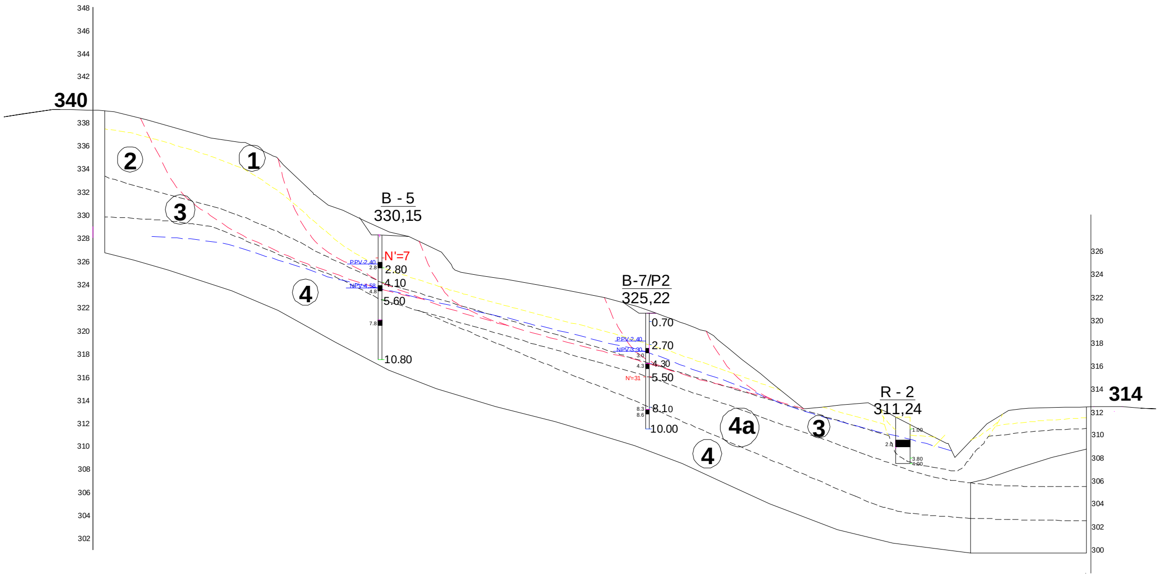

Figure 2. Engineering geological profile of terrain on landslide
1, clayey sediments, 2. silty - sandy clay, 3. tuffites clay,
4. sandstones and conglomerates, 4a. sandy clay

Research works are limited to a small part of the slope, ie part that is affected by landslide from its top, where are individual objects, to a local stream. On the left side is a village cemetery. Total area of the terrain is approximately 1 ha. Inclination of terrain surface that is damaged with sliding process, is partially modified, but in general can be estimated that the natural inclination of the slope is around 25^0.

Sliding has threatened several rural households whose housing objects and additional facilities are located near the frontal landslide scar. In bottom part of the slope, local streem is cut in between the slope and hill, where is located village cemetery. The stream is torrential and during heavy rainfall overflows from the river bed and floods the lower parts the terrain. If the sliding intercepts its bed, the cemetery is directly affected not only from the flood, but also from the sliding, given that is located on a conditionally stable slope.

The average width of the researched terrain is about 100 m, and length is about 120 m which in relation to the affected area of sliding, ranks it among the medium-sized landslide. In relation to the constructed facilities that may be threatened (houses, cemetery and road), the landslide is of high risk.

The biggest devastation of the terrain occurred in the central and eastern part of the slope ie at the bottom of residential buildings. Frontal scar is formed in the immediate vicinity of objects. The height difference between objects and beginning of sliding is around 2,0 – 3,0 m, and minimal distance in the horizontal direction is about 10 m, figure 3. The scar continually extends in the length of about 45 m, direction east - west. The height is about 1.0 m on the western side, in the area of facilities is about 2.0 - 3.0 m, while on the eastern side is lost on the local ridge between the the researched and neighboring slope. In the zone of the borehole B - 8 / P1 branches and a longer arm can be discerned all the way to the far east side of slope. Along scar length are registered washings, and in bottom part of the scar are present changes of small surfaces that are important for further development of sliding process, figure 3 .

Figure 3. Frontal scar and bottom part of slide

Next sliding scar also spreds in direction east – west but its contours are not clearly expressed along the entire length. In the hinterland, borehole B – 4 height is about 1,0 m and in the immediate vicinity of borehole is formed a secondary scar height to 0,5 m. Further to the bottom part of slope, in the zone of borehole B – 7/P2, is formed one more scar whose contours are clearly visible on the eastern part of the slope, but does not affect the middle part.

Among the other microforms characteristic for landslides are present many sags, mostly in the western part of the slope. Sliding formed many plains and dents that restreined water, soaked the clays surface and in this way increased the risk of slipping. In hypsometrically lower parts of the slope are present numerous open cracks, making this part unstable and prone to new movements of terrain.

Landslide in relation to depth of sliding plane is shallow, depth of 5,0 m, belongs to detrusiv landslides because it is formed from the top of the slope. Seen as a whole, it can be concluded that the causes of sliding are primarily in the natural structure of the terrain, that was even before active process of sliding, in a state of unstable equilibrium. Surface and near surface clays are during greater part of the year under the influence of groundwater. Considering that the terrain is not cultivated during dry periods, large open cracks are formed on its surface. During the rainy intervals the water does not get to filtrate down the slope, and part of it passes through the open cracks to its interior. Over time, the soil is saturated with water, whereby is undermined natural state of balance due to voltage changes in the soil, leading to the launching of sediments, ie creating a sliding process, and its appearance is landslide as specified. Also, during larger rainfall, local stream which is of torrential character considerably erodes the bottom of the slope and disturbs the stability in that part. This can reflect on endangering the slope on the left side of the stream where is a village cemetery.

GEOTECHNICAL CHARACTERISTICS OF THE TERRAIN

Construction of the terrain in the part of landslides is quite heterogeneous. Featured layers were observed as two environments:

- plastic environment consisting of poorly bonded rocks – clayey sediments
- plastic to quasiplastic environment with lenses and interlayers of friable environment
  - plastic to quasiplastic environment consisting of completely degraded clayey sandstones and conglomerates, and te clayey gravel and sand
  - friable environment consisting of sandstones of preserved structure

Within these environments are parsed four (4) lithological types and a complex of sediments. For all are determined physical and mechanical parameters and adopted mean values for geostatic calculations [8].

Leyer 1 – clayey sediments that are characterized by low plastic clays of CL group. Adopted values of physical - mechanical parameters for geostatic calculations are:

- bulk density $\gamma = 19{,}0\ kN/m^3$
- cohesion $c = 20{,}5\ kN/m^2$
- angle of internal friction $\varphi = 17^0$
- compressibility modul $Mv_{(\sigma=100\text{ - }200kPa)} = 5449\ kPa$

Leyer 2 – silty - sandy clay, low to high plastic of CL – CH group, with the state of plasticity ranging from soft to hard, for which adopted values of physical - mechanical parameters are the following:

- bulk density $\gamma = 18{,}4\ kN/m^3$
- cohesion $c = 17{,}5\ kN/m^2$
- angle of internal friction $\varphi = 15{,}3^0$
- compressibility modul $Mv_{(\sigma=100\text{ - }200kPa)} = 2522\ kPa$

Leyer 3 – Tuffites clay in amend with the silty - sandy clay, low plastic of CL grupe, generally in a state of hard plastic. Adopted values of physical - mechanical parameters are:

- bulk density $\gamma = 18{,}8\ kN/m^3$
- cohesion $c = 38{,}8\ kN/m^2$
- angle of internal friction $\varphi = 24{,}2^0$
- compressibility modul $Mv_{(\sigma=100\text{ - }200kPa)} = 2766\ kPa$

Leyer 4 – sandstones, conglomerates, clayey gravels and sands, coarse clastic sediments of rocks complex of terrain substrate. They are mostly clayey and sandstones and conglomerates are completely degraded, usually fragmented. Gravels and sands are poorly sorted, well compacted and water bearing. The values of the adopted parameters are the following:

- bulk density $\gamma = 21\ kN/m^3$
- cohesion $c = 5\ kN/m^2$
- angle of internal friction $\varphi = 35^0$
- compressibility modul $Mv_{(\sigma=100\text{ - }200kPa)} = 20\ 000\ kPa$

Leyer 4a – sandy clay, low plastic, of CL group. Contains fragments of rocks and pebbles of gravel up to 10 cm. Adopted values of physical - mechanical parameters for geostatic calculations are the following:

- bulk density $\gamma = 21\ kN/m^3$
- cohesion $c = 20kN/m^2$
- angle of internal friction $\varphi = 20^0$
- compressibility modul $Mv_{(\sigma=100\text{ - }200kPa)} = 5000\ kPa$

Based on the adopted values of physical - mechanical parameters, obtained by laboratory tests, geotechnical model is set for geostatic calculations, with some adjusted adopted parameters, for extra safety of objects, table 1.

Table 1. Geotechnical model of the terrain

Mark of the layer	Short name of the layer	Bulk density γ (kN/m^3)	Angle of internal friction φ^0	Cohesion c (kN/m^2)	Compressibility modul Ms (kPa)
1	clayey sediments	19,2	17	20	4246
2	silty sandy clay	18,4	15,3	17,5	1712
3	tuffites clay	18,8	24,2	38,8	1095
4	sandstones, conglomerates	20,0	35	5	20000
4a	sandy clay	19,0	20	20	5000

GEOTECHNICAL ANALYSIS OF SLOPE STABILITY

As the final phase of research of landslide, geotechnical analysis was carried out which included the calculation methods for calculating stability of the slope by using the software package Plaxis 2D ver.8.5. Calculation is given for the characteristic profiles that correspond to direction of movement of the sliding body. Input parameters of the geotechnical model of the slope are the results of detailed engineering and geological research and testing [4,9,10,11].

Calculation of stability is based on the final elements method. The behavior of the surface layers, the infirm of substrate and substrate are described with elastic - plastic Mohr - Coulomb's method of soil.

Stability calculation is based on the reduction of entered parameters of cohesion and angle of internal friction φ until the moment when occurrs collapse, ie when the shear strength of the soil falls on critical value, less than shear value in the soil. Thereby, is formed the shape of the critical plane on which occurs sliding. That sliding plane is formed by a series of model points where the voltage reached a critical state.

The value of parameters c and φ in specific calculation step, we can determine by following changes in the value of factor ∑Msf during the calculation.

Factor ∑Msf represents the following relation:

$$\sum M_{sf} = \frac{tg\,\varphi_{input}}{tg\,\varphi_{reduced}} = \frac{c_{input}}{c_{reduced}}$$

$\sum Msf=1$ – state of labile equilibrium
$\sum Msf<1$ – state of soil break at sliding plane
$\sum Msf>1$ – will not occur the break of the soil, but can be determined safety factor on sliding of observed slope

For calculation analysis of slope stability was applied Eurocode 7 EN 1997-1

Calculation analysis of stability

On profiles 1, 2 and 3 were made geotechnical models with selected parameters of soil whereby all layers of soil were completely saturated with water up to the line of terrain. For those conditions were obtained safety factors Msf < 1 for critical sliding plane made with method c/φ reduction, which indicates that the soil is not stable. The same confirm reality on the ground. Characteristical profile 2, is shown on figure 4.

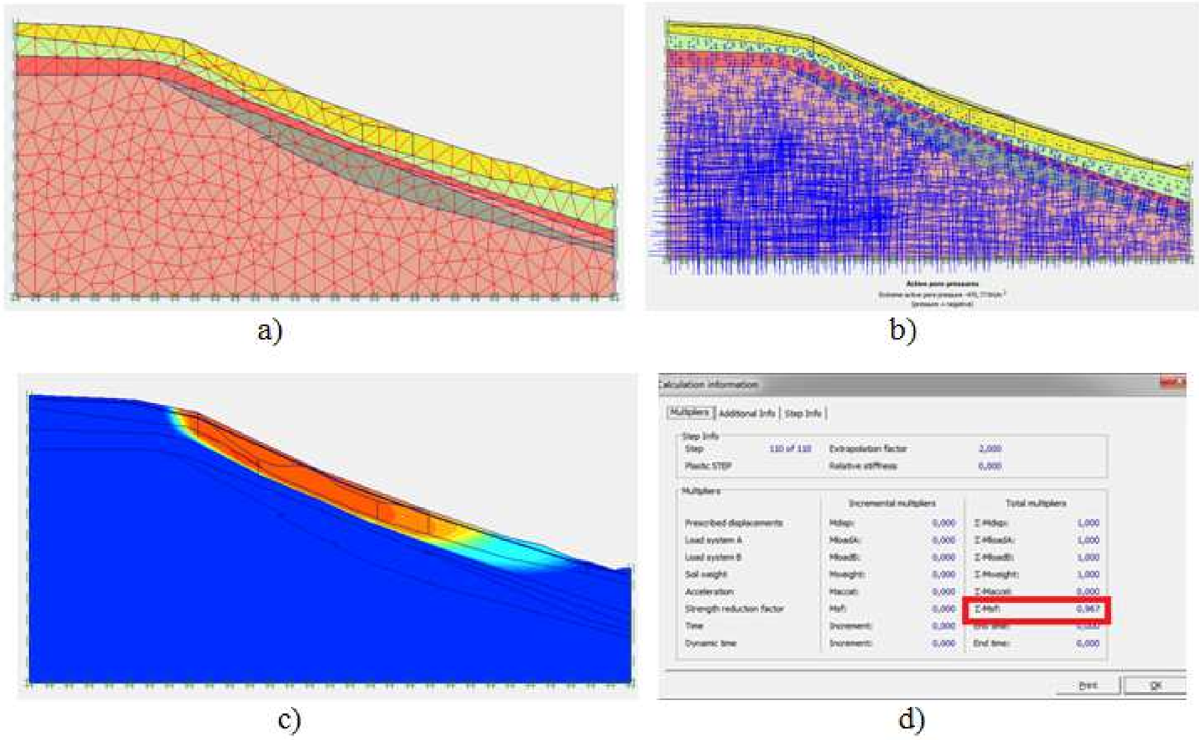

Figure 4. Characteristic profile 2, stability analyzes
Slika 4. A typical profile 2 stability analysis
a) finite element mesh, b) an active pore pressure,
c) the potential sliding plane with a safety factor MSF = 0.967, d) part of the listing calculation

PROPOSITIONS FOR SANATION MEASURES

Proposals for sanation measures relate to the controlled drainage - decreasing level of groundwater of entire site that is affected by sliding [9,12,13]. Drains will be brought from the zone of residential buildings to the stream at the bottom of the slope. Filling of drains is of crushed stone, to a depth of overtake of non moving parts of the terrain. Number and spatial position of drains should be placed in accordance with the calculation evidence of slope stability.

To stabilize the terrain is necessary to regulate the stream bed in the bottom of the slope, in the way that bottom part of the slope is ensured from eroding during the torrential waters.

Surface of sanitized slope regulate in terms of its inclination in order to achieve conditions for its quick and easy surface draining. Sanation works perform during the dry season, since the tuffites clays of layer 3 are expansive when soaked with water.

CONCLUSION

Landslide in the village Suljendić is located on the northern slopes of Majevica mountain, on conditionally stable slope, at whose top is a small populated village. The slope maintained for years conditional stability, to the emergence of several days of rainfall in May 2014. Then, it was disturbed natural equilibrium in the terrain, and formed a landslide at the top of the slope that threatened a populated village, and at its bottom a local creek and the village cemetery.

Conducted research in the form of exploratory boreholes and trenches, and laboratory tests on taken samples, enabled separation of two engineering geological environments, where are parsed four lithological types and a complex of sediments. For every lithological type or layer are determined physical-mechanical parameters and adopted mean values for geostatic calculations. In order to monitor the state of the groundwater level, in characteristic boreholes were built piezometers. For monitoring of movement in sliding zone were installed inclinometers. The depth of the sliding plane is up to 5,0 m, and a landslide is of detrusiv type, since it is formed from the top of the slope.

Analysis of slope stability was performed on three profiles where colculation confirmed instability of the slope for the conditions of adopted paramaters. Obtained are safety factors Msf < 1. The calculation was performed by using the software package Plaxis 2D ver.8.5, and for calculation analysis of slope stability was used Eurocode 7 EN 1997-1.

Proposals of sanation measures included the setting of controlled drainage for reduction of the groundwater level of entire site affected by sliding. Spatial position of drains harmonize when by calculation is proved the stability of the slope. Also, for stabilization of terrain is necessary to perform regulation of the stream bed at the bottom of the slope, in order to secure the same from eroding, during torrential waters.

(Received August 2016, accepted September 2016)

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