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ENGINEERING GEOLOGICAL AND GEOTECHNICAL CHARACTERISTICS OF LANDSLIDE IN GORNJI HRGOVI, MUNICIPALITY OF SREBRENIK

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SUMMARY

Natural disasters during May 2014 caused a flood of water outside the unregulated bed of the river Tinja in the local area of Gornji Hrgovi. The flood effect affected the undermining and destruction of the foot part of the slope, reactivation and regressive development of the landslide, which was manifested by further secondary "breaking" of the sliding body towards the hypsometrically top part of the slope and intersection of the primary water pipeline.

Gravitational displacement of the colluvial material resulted in significant degradation of the agricultural land surface in the central part of the unstable slope, while in the accumulation zone the accumulated slide mass destroyed the earth road communication. Based on the conducted geotechnical researches, determined engineering-geological and hydrogeological composition and properties of the terrain, the zoning of the terrain according to the degree of stability was performed, important recommendations and conditions of the landslide remediation method were presented.

Key words: *landslide, geotechnical researches, landslide remediation*

INTRODUCTION

Due to the great impact on space, people and property, landslides are becoming an increasingly common topic and area of research by experts of various profiles, and only a multidisciplinary approach enables development of complex knowledge about landslides. In Tuzla Basin, there are several number of examples where engineering geological mapping was conducted based on which were identified landslides of different levels of activity and given were subjective assumptions about where landslides could occur in the future, and without prior conducted research and testing or geotechnical engineering missions.

Effective management of geo-hazards is only possible through a systematic study approach, cadastral processing and taking appropriate measures. Unfortunately, our country has not yet defined institutional framework for landslide management, nor the methodology for assessing landslide hazards. Therefore, for the development of an appropriate method of hazard and landslide risk assessment, there should certainly be adopted introduction of modern methods of hazard assessment based on deterministic methods. Experience to date indicates attempts to record landslides using various forms to fill in landslide data in which a significant amount of expert data is omitted or the answers are very general, so many are not relevant for further study, processing or integration into a digital database.

GENERAL PART

During the natural disasters that struck this area in May 2014, the water level of the river Tinja increased, when the bridge in Ormanica and the road to the settlement of Gornji Hrgovi were flooded, which prevented the residents of the surrounding settlements from accessing the Tuzla-Orašje highway.

Heavy rainfall, which was far above average, caused the reactivation of landslide of the north-western exposure, spatially located between 44°46'33.55" north latitude and 18°31'20.30" east longitude according to Greenwich Mean Time (Figure 1).

Figure 1. Geographical location of the research area

Based on the distribution of activities and development of the fracture surface, the reactivated landslide belongs to regressive landslides group, complex landslides with a combination of three types of movement.

During the engineering geological mapping, it was determined expressive imbalance of masses in the central part of the slope created by landslide reactivation in several phases [1]. The ridged stable shape of the terrain is represented by the hypsometric peak parts of the slope. The north-western exposure of the 443.30-meter-long slope is followed by the inclination of the terrain in the range of 12^o to 14^o. The continuous inclination of the slope is interrupted by sinkholes and stepped terrain forms (Figure 2) which indicate multiphase regressive sliding.

Figure 2. Multiphase landslide development

By engineering-geological mapping of the terrain in the foot part of the slope, gravitational pushing of colluvial material and formation of the accumulation zone in relation to the unmoved surface of the terrain was noticed. The elevation of the landslide foot is 137.16 m above sea level. The absolute elevation of the landslide front is 230.27 m above sea level. The relative height difference between the font and the foot of the landslide is 93.11 m. In the part of the terrain where the slope of a slight inclination of 5-7^o successively passes into the plain terrain closed by the river Tinja, there are no traces of destruction and instability of the terrain.

After the activation of the landslide, in the organization of the municipality of Srebrenik, emergency intervention remediation measures were carried out [2], which were reflected in the drainage of surface rainwater (concentrated dug channels through the landslide body). With the help of mechanization, the formed colluvial material was partially removed in order to relieve the slope, but due to the complex mechanism of sliding distribution, physical and mechanical properties of the covering material, as well as sliding depth, limited intervention measures did not give significant stabilizing effects.

Paleocene-Eocene sediments participate in the geological composition of the area, and transgressive Sarmatian sediments within [3]. Paleocene-Eocene sediments are represented by stratified sandstones and marls, and Sarmatian deposits by clays and limestone.

Hydrogeological characteristics of the subjected slope were analyzed both for the purpose of determination of the general engineering geological properties of the terrain, reconstruction of the landslide mechanism, regionalization of the terrain according to the degree of stability, and for the needs of landslide remediation.

The impermeable layer at this site is marl. Geomechanical tests have determined water-permeable materials in the upper horizons of the formed colluvial cover - (brown clay, yellow-brown dusty and sandy with traces of groundwater movement, concretions of organic material and conglomerate inclusions; liquid, easily kneading consistency). In the hydrogeological terms, the colluvial cover has the role of a hydrogeological conductor [4]. The eluvial-deluvial cover is made of brown-gray marly clay (medium to hard kneading consistency) which represents medium water permeable media. The sliding body is flooded in the central and foot part of the slope, which is one of the causes of the formation of instability.

During the continuous penetration test performance in the geomechanical well B4, a sudden sinking of the tool was recorded in the interval -5.20 to 7.00 m from the surface of the terrain in the horizon (decomposed limestone with the content of the clay component). In geomechanical wells B6, B9, B10, swelling of clays in the upper horizons of the cover was registered. Based on the obtained results in the research area, 5 engineering geological units were singled out; out of which three belong to the geological substrate, and the remaining two to the groups of cover.

The geological substrate is represented by sandstones, oolithic limestones and marls.

Covers

The eluvial-deluvial cover (ed) was formed as a result of surface wear out of the geological substrate formations and partial leaching and accumulation of decomposed matter. The lithological composition of this cover is consisted of brown-gray marl clays of medium kneading and gray clays with a crumbly geological substrate (difficult to knead to a firm consistency). The thickness of the cover is variable, which can be seen on the engineering geological profile (Figure 3).

The sediments formed by sliding (k) were formed as a result of the colluvial process, during which part of the eluvial-deluvial cover slided, and the accumulation of soil masses in the central and foot part of the landslide. The lithological composition of the colluvial sediment consists of brown, yellow-brown dusty-sandy clays with traces of groundwater movement, concretions of organic material (liquid, easily kneading consistency). It is characterized by poor geotechnical characteristics and a higher degree of flooding due to the influence of groundwater and surface water (atmospheric and wastewater).

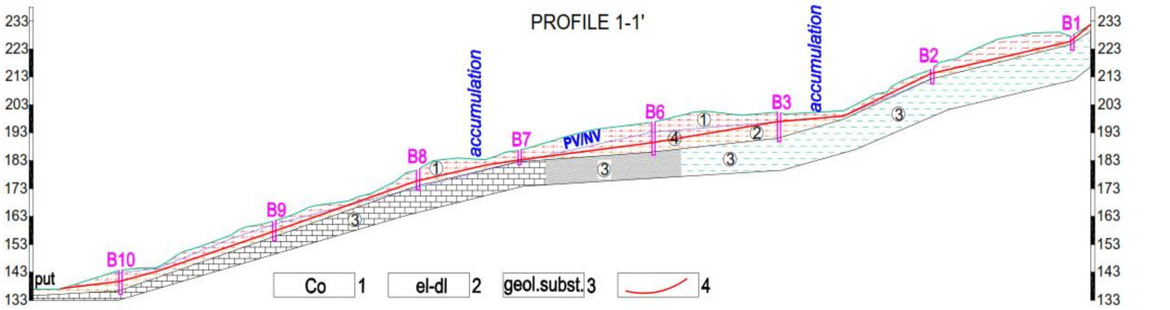

Figure 3. Engineering geological profile 1-1'
1. Colluvial sediment, 2. Eluvial-deluvial cover, 3. Geological substrate, 4. Sliding plane

The embankment (n) was formed in order to establish the road communication of the settlement of Gornji Hrgovi.

A detailed engineering geological map (R 1: 1000) was made after geomechanical tests and hydrogeological research. As a basis for its production, a geo-referenced map in the scale of 1: 1000 of the wider influential part [1,5,15] of the terrain was used, which served for the zoning of the terrain according to the degree of stability (Figure 4).

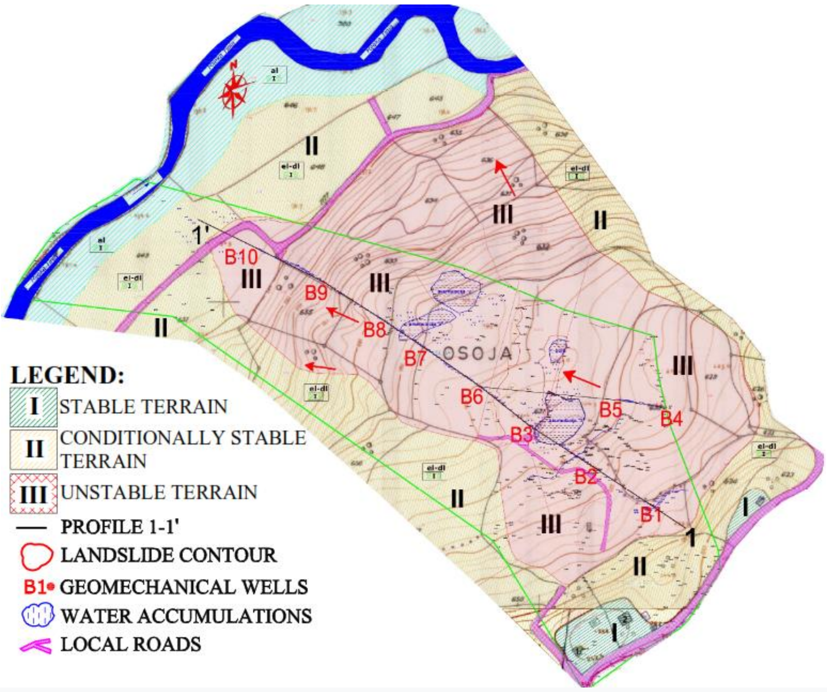

Figure 4. Rheonization of the terrain according to the degree of stability.

With engineering-geological mapping of the terrain according to the surface of the slided colluvial mass, subjected landslide belongs to a very large landslide. According to the type of process on the slope [6,7], the landslide is of the rotational type (multiphase sliding and overturning of blocks). According to the size - the surface of the sliding body, the landslide is very large. According to the volume of the sliding body, the landslide is large. According to the morphology of the sliding body, it belongs to the amphitheater type of landslide. According to the state of activity, it has been quiet. According to the structure of the slope and the position of the sliding surface, it belongs to the consequent landslide.

RESEARCH MEATHODS

For the purpose of defining geotechnical parameters, composition and properties of the terrain, the following research and tests were performed:

- Geodetic surveys,
- Exploratory drilling,
- Standard penetration testing,
- Laboratory tests,
- Slope stability analysis,
- Engineering geological mapping,
- Reonization of the terrain according to the degree of stability,
- Elaboration

Within the geodetic survey, a situation in the state coordinate system was made at a scale of 1: 500. The locations of exploration wells expressed in absolute coordinates were recorded. From the exploration works, ten wells were drilled with Dolap set with the performance of a continuous standard penetration test along the entire depth of the well. Drilling was performed in the period from 15.-30. 09. 2018. Ten wells marked from B1 to B10 were drilled with a machine set with continuous core extaction. The core was stored in appropriate boxes, mapped, determined and photographed by a geologist. The diameter of the wells in the cover materials is 101 mm, and in the geological substrate, at least 86 mm. Disturbed and undisturbed samples were taken from a completely fresh extracted core and properly preserved. Samples taken in-situ, ie in the medium, are at intervals in the well, so that all varieties of soil and rocks that occur during the research are represented.

During the geomechanical tests, hydrogeological observation of the occurrence of groundwater acting in the soil was performed. Groundwater levels were measured 24, 48 hours after the end of the test.
Laboratory tests were performed in order to define the classification and physical-mechanical characteristics of the soil [8,9,10], according to the valid procedures in the accredited laboratory "GIT" Institute for Civil Engineering, Building Materials and Non-Metals Tuzla: Accreditation "BATA" is registered under number LI-04-01.

- Natural humidity was determined by the procedure: BAS ISO / TS 17892-1 Geotechnical investigation and testing - Laboratory soil testing - Part 1: Determination of humidity
- The bulk density of the soil is determined by the procedure: Geotechnical investigation and testing - Laboratory testing of soil - Part 2: Determination of density of fine - grained materials.
- Specific mass, at the prescribed temperature and humidity of the environment: determined by the procedure: BAS ISO / TS 17892-3.
- The Atterberg consistency limits represent the yield, plasticity and shrinkage limits and are determined according to BAS ISO / TS 17892-12.
- The direct shear test was performed in an apparatus with controlled shear deformation, at three vertical loads. The analysis is used to determine the parameters of shear strength, cohesion c (KNm^{-2}) and internal friction angle φ (^{o}). Test was performed in accordance to stipulations of BAS ISO/TS 17892-10 Geotechnical investigation and testing - Laboratory testing of soil - Part 10: Direct shear test. The shear resistance parameters for the soil were determined for translation directly with a controlled speed of deformation rate of dimensions 60x60 mm and height 25 mm. The samples were made in the undisturbed state and consolidated under vertical load σ': 50, 100, 150 KN^{-2}, shear resistance ζ: 50, 100, 150 KNm^2. Tangential stresses are increased in degrees $\Delta=\sigma'/40$ in time intervals Δt_1 from 5 to 30 minutes. Shear rate 0.3048 mm/min, dynamometer constant 0.034 mm/kp. The obtained values of shear strength and parameters c and φ obtained on soil samples for the respective intervals range from 5 to 9 KNm^2 for cohesion (c) and from 18 to 19^o for the internal friction angle (φ). Proper sampling gives representative values of material properties (for a given realistic case). For the calculation of slope stability, input geomechanical parameters were adopted, which reflect the most unfavorable conditions on the slope.

Slope stability analyzes were performed with recorded terrain elevations, pore pressure coefficients for natural and drained slope according to the Janbu method, on a licensed computer program of the Faculty of Mining, Geology and Civil Engineering in Tuzla. The method is based not only on the conditions of balance of forces along the x-axis, but also on the moment equilibrium for each lamella. This program enables the change of input data and slope geometry, which enables intervention during the calculation, and quickly and very clearly studies the impact of changes in the input data and obtains an optimally dimensioned slope cross section.

Based on the conducted research, tests and obtained results, a detailed engineering geological map in the scale of 1: 1000 was made. The engineering geological map contains all relevant data for design and is prepared according to the Instructions for the preparation of engineering geological maps (Instructions of the International Association for Engineering Geology - IAEG).

Within the research area, the terrain was reonized [9,10] according to the degree of stability with separate zones: stable, conditionally stable and unstable terrain, according to the area of representation (m2) and percentage (%).

After the completion of field works and laboratory tests, the cabinet processing, analysis and interpretation of the collected data and the obtained results with their elaboration were performed.

RESULTS AND DISCUSSION

The paper presents the performed analysis of slope stability for profile 1-1' with length of 443.30 m and slope inclination from 12^o to 14^o. With proper field and laboratory testing, a selection of representative samples was made that reflected the most unfavorable conditions prevailing on the slope. For the geotechnical calculation [1,11], the geomechanical parameters are shown (Figure 5): bulk density, cohesion, tgφ, pore pressure coefficient for each layer individually: 1) sliding mass, 2) cover and 3) geological substrate.

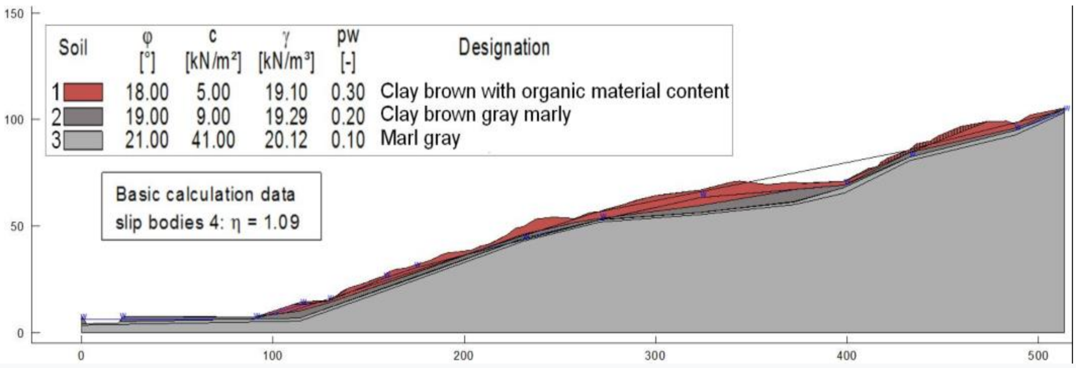

Figure 5. Model for stability analysis (slope at the time of research)

The safety factor of the natural slope in (during research time) is Fs = 1.09. The natural water content in the cover materials and the formed colluvial mass has a great influence on the above parameters.

On the analyzed unstable slope, the interaction of surface - precipitation, accumulated - standing (sinkholes) and groundwater adversely affects the reduction of normal effective stresses and thus soil strength. Based on the identified causes, slip mechanism and vulnerability of the research area, the selection of the optimal method of slope stabilization was approached [12]. With redistribution of masses, removal of excess earth material from the central part of the sliding body, surface and deep drainage during rotational sliding reduces the moment of gravity of the sliding body [13] with respect to the center of rotation and thus increases the safety factor (Figure 6).

The safety factor with the stated measures of the rehabilitated slope is FS = 1.89 (stable). By arranging, recultivating and draining the slope, it will provide a reduction of the pore pressure in the zone of the critical sliding surface.

For the needs of water supply of the settlement, it is necessary to perform relocation of the primary water supply pipeline on the stable part of the slope. Upon completion of remediation, it is necessary to establish instrumental monitoring [14] of follow up over a period of at least two hydrological years [15].

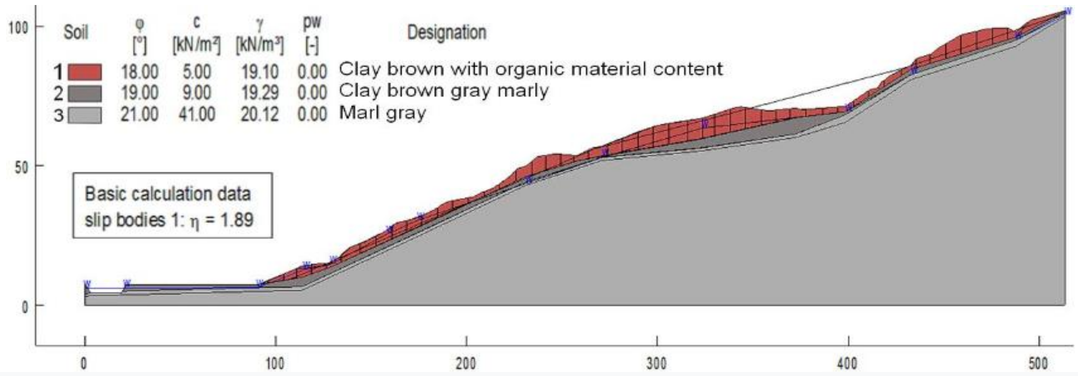

Figure 6. Model for stability analysis (repaired condition), profile 1-1'.

The safety factor with the stated measures of the rehabilitated slope is FS = 1.89 (stable). By arranging, recultivating and draining the slope, it will provide a reduction of the pore pressure in the zone of the critical sliding surface.

For the needs of water supply of the settlement, it is necessary to perform relocation of the primary water supply pipeline on the stable part of the slope. Upon completion of remediation, it is necessary to establish instrumental monitoring [14] of follow up over a period of at least two hydrological years [15].

In the engineering geological map (Figure 4), all three categories of terrain are spatially defined and marked according to the degree of stability:

Unstable terrain

This category of terrain represents the part of the research area that is affected by the sliding process. The unstable part of the terrain occupies an area of 82,680.63 m^2, which represents 71.40% of the total area of the research area, which amounts to 115,762.61 m^2. In an unstable category of terrain that is spatially clearly defined, the construction of facilities cannot be performed until detailed geotechnical investigations of the entire endangered area are performed. In this part of the terrain, the terrain must not be cut down or larger embankments may not be formed.

Conditionally stable terrain

This category of terrain, when isolated, occupies an area of 30,573.84 m^2, which is 26.43% of the total area of the research area. This category of terrain, with the prescribed measures and performed remediation, can be converted into a stable category of terrain.

Stable terrain

This category of terrain occupies an area of 2,508.14 m^2 or 2.17% of the total area covered by the research and is characterized by favorable geotechnical characteristics. Objects located in the engineering geological map, marked with numbers 1 and 2, can be legalized.

CONCLUSION

Based on the results of conducted engineering geological and geomechanical research, determined engineering geological and hydrogeological composition and properties of the terrain, represented degree of exogenous geological processes, regionalization of the terrain according to the degree of stability, recommendations and conditions for remediation methods of unstable and conditionally stable terrain are given. Based on the regionalization of the terrain according to the degree of stability, it is possible to adjust the purpose of land use to geological conditions, which will certainly minimize material damage.

To date, the projected remediation measures have not been initiated at this site, although they have been marked as urgent due to the endangerment of material goods. Unfortunately, in the most cases, the implementation of the proposed remediation measures depends on the available funds of the community. Although landslides have become a problem that we often encounter, not enough is being done for preventive measures in order to prevent the emergence of new ones and reactivation of existing ones.

Landslides, as geo-hazards, have proven to be particularly problematic due to the lack of clearly prescribed competencies of various institutions that primarily deal with them, as well as the lack of strategies for their management, lack of information and data (cadastres), forecast maps (hazards and risks), and low knowledge of landslides and their consequences in the general public and at various levels of government.

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