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ENGINEERING GEOLOGICAL AND GEOTECHNICAL CHARACTERISTICS OF THE LANDSLIDE IN THE SETTLEMENT OF ZUKIĆI, MUNICIPALITY OF KALESIJA

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SUMMARY:

In the settlement of Zukići in May 2014, during a natural disaster, a larger landslide was activated, which affected damages on the part of the local asphalt road, what has resulted as the interruption of road communication through the settlement.

After the activation of the landslide, no planned remedial measures were carried out on this part of the terrain, except for local interventions to remove formed colluvial material in order to relieve the slope, level the terrain, as well as backfill to achieve the appropriate level of the road in order to make it passable.

Based on the conducted geotechnical investigations, defined geological engineering and hydrogeological composition and properties of the terrain, the terrain was rezoned according to the degree of stability, important recommendations and conditions for landslide rehabilitation were presented.

Key words: landslide, geotechnical research, landslide rehabilitation

1. INTRODUCTION

Due to the large impact on space, people and property, the management of geohazards is only possible with a systematic approach to study, cadastral processing and taking appropriate measures. In the area of the Tuzla basin, there are a number of examples where engineering geological mapping was carried out, based on which landslides of different degrees of activity were identified and subjective assumptions were given about where landslides could occur in the future, without simultaneously carrying out research and tests, i.e. geotechnical engineering missions. In addition, there is no unique cadastre of landslides for the TK area, because the data for individual cities/municipalities differ significantly in terms of content, the way they are presented on cadastral sheets and overview topographic maps.

Therefore, for the development of an appropriate method of hazard and landslide risk assessment, the introduction of modern hazard assessment methods based on deterministic methods should definitely be adopted. This research approach, based on the results of detailed research, allows the application of a mathematical model and the calculation of stability factors to rezone the terrain according to the degree of stability and to separate the zones: unstable, conditionally stable and stable terrain.

It is necessary that the approach to the study of landslides should be carried out through appropriate regulations as binding and on the basis of a unique methodology for the creation of landslide cadastres, in the area of all local communities of the Tuzla Basin, so that in the next phase of the elaboration of spatial and urban plans, an objective landslide hazard map and a surface categorization map can be made according to the intended use of the space. In this way, it will be possible to realize the constant monitoring of landslides and the integration of landslide cadastres into a unique information system at higher levels.

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2. GENERAL CHARACTERISTICS

In the settlement of Zukići, in May 2014, due to heavy rainfall that was far above the average values, it caused the activation of a landslide, which affected the damage of part of the local asphalt road, which was reflected in the interruption of road communication through the settlement. The researched location is placed on the slope part of the terrain extending east-west, spatially located at the geographical coordinates of 44°27′7.55″ north latitude and 18°56′24.62″ east longitude according to Greenwich. The location of the local road vertically intersects the extension of a large amphitheatre-shaped slope, which is characterized by varying degrees of stability.

At the entrance to settlement Zukići from the direction of the elementary school "Memici" in Zukići and the local mosque, there are other separate and partially connected larger or smaller landslides, which affect the damage to residential buildings in different parts of the settlement, representing special spatial entities for research and rehabilitation. The research covered a part of the slope that represents one morphogenetic unit (part of the subject local road in length of about 100 m), with an average absolute terrain elevation of about 374 m.a.s.l. The configuration of the researched terrain was observed and displayed using a digital orthophoto plan and a digital 3D terrain model (Figure 1).

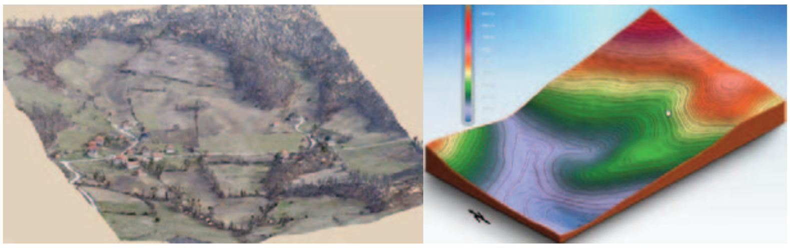

Figure 1. Orthophoto plan and digital 3D terrain model in the researched area

Based on the conducted research, the structure of the natural slope and the position of the sliding surface up to 3.40 m from the ground surface, this landslide belongs to the asequent type, which indicates a shallow rotational type landslide with an approximately circular cylindrical sliding surface, conditioned by different physical-mechanical properties and a simple relocation mechanism [1]. Through engineering geological prospecting, observed were terrain forms wich occured as a result of natural and anthropogenic processes. Shear tension deformations (extension cracks perpendicular to the direction of movement of the sliding mass) were observed on the route of the road. Above the road (figure 2), on the sliding body can be seen recognizable relief inverse forms which are manifested in the form of transverse cracks with a jump of up to 1.0 m, as well as bell-shaped protrusions caused by the multiphase gravitational movement of colluvial material.

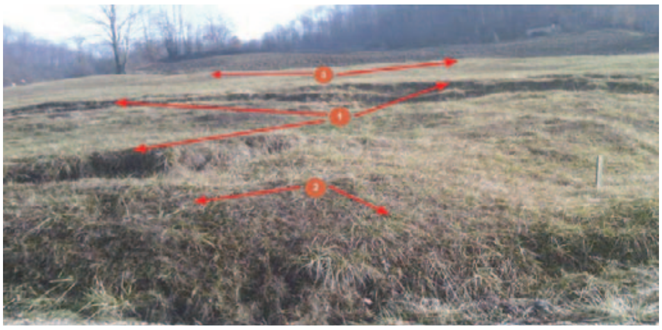

Figure 2. Inverse forms of relief: 1) transverse cracks with a jump of up to 1.0 m, 2) convex and 3) polyphase accumulation of colluvial material

In a wider area, according to the geomorphological classification, relief forms created by slope processes, fluvial relief and anthropogenic relief can be distinguished. Slope relief is present in most of this area. The slope is of western exposure, typically exogenous type, hypsometrically developed towards the east to the watershed of the terrain where the terrain bends in the opposite direction with an average absolute elevation of about 435 m.a.s.l. In general, the slope is characterized by a variable slope if local deviations are excluded, in the interval of 5° (foot part of the slope), 9° (area of the local road) to the hypsometric peak part of the slope of about 12°.

Based on the morphometric characteristics, the western foot of the mapped landslide is closed by the northern occasional and southern permanent local stream, with an average absolute elevation of about 340 m.a.s.l., which represents the crossing of the slope with a gentle slope of up to 5° and the alluvial plain of the Bukovica River. The relative height difference of the hypsometric peak and foot part of the slope is about 95 m.

After the activation of the landslide, no planned remedial measures were carried out on this part of the terrain [2], except for local interventions to remove formed colluvial material in order to relieve the slope, levelling of the terrain, and filling and achieving the appropriate level of the road in order to make it passable. After the activation of the landslide in May 2014 , the owner of the plot of land no. 1022/1 K.O. Memići self-initiatively carried out shallow drainages of questionable depth, perforations, rules of "filter layer" and absorbent recipient. These rehabilitation works did not have a stabilizing effect on the endangered area.

In geological composition of this area includes are rocks of Middle Miocene age [3], represented by coarse-grained layered clastites (sandstones, marls, and subordinate conglomerates), as well as Quaternary sediments, which are mainly represented by clays.

Hydrogeological characteristics of the slope in question were analysed both for the purposes of determining general engineering geological properties of the terrain, reconstruction of the sliding mechanism, rezoning of the terrain according to the degree of stability, and for the purposes of rehabilitating landslides.

The water resistant layer in this locality is represented by marls. Geomechanical tests determined water-permeable materials in the upper horizons of the formed colluvial cover - (dusty clay with concretions of organic material and inclusions of conglomerate). In the hydrogeological sense, the colluvial cover plays the role of a hydrogeological conductor [4].

The eluvial-deluvial cover is made of calcitic clays which represent medium water-permeable media.

During the performance of exploratory geomechanical boreholes marked (B5, B7, B9), constant wetting, swelling and weakening of the physical-mechanical characteristics in the horizon up to 3.40 m from the ground surface was determined. During the geomechanical test, the occurrence of underground water acting in the soil was determined, as well as the final levels of underground water, measured after 24 and 48 h from the end of the test.

In all boreholes, a static water level was recorded that ranged from 1.50 to 4.20 m from the ground surface, which indicates that the sliding body is waterlogged, as well as that the covering materials contain a higher percentage of natural moisture, which is one of the causes formation of landslides in this area.

As part of the field investigation works, after geodetic survey, engineering geological mapping of the terrain was carried out. Based on the results obtained from geomechanical tests (9 boreholes with continuous standard penetration tests throughout the depth of the well), as well as hydrogeological and laboratory tests, a detailed engineering geological map R 1:1000 was prepared. The landslide is connected in the central and foot part of the slope with two separate arms K1 and K2. Due to the limited degree of research due to the project task, the separated arm of the K2 landslide, where there are a larger number of individual residential and auxiliary buildings, has not been geotechnical researched. As such, it represents a special spatial unit for further research and rehabilitation.

Based on the obtained results of research and testing, 3 engineering geological units have been identified in this area, one of which belongs to the geological substrate, and two to the cover group.

The geological substrate is represented by sandstones, oolitic limestone and marls.

Cover layers

The eluvial-deluvial cover (ed) was created as a consequence of the surface wear of geological substrate formations and partial washing and accumulation of decomposed material from the higher parts of the slope in the central and lower parts. The lithological composition of this cover consists of brown dusty clays, grey calcitic clays with a medium compressibility and grey clays with a friable geological substrate, which are difficult to compress. According to GN-200, this cover belongs to category III. The thickness of this cover is variable, as can be seen on the engineering geological profile (Figure 3).

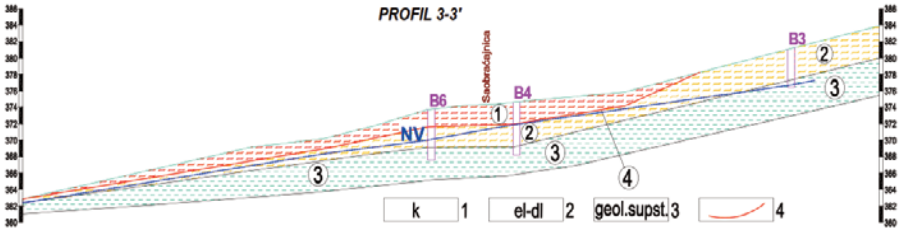

Figure 3. Engineering geological profile 3 - 3′
1. Landslide deposit, 2. Eluvial-deluvial cover, 3. Geological substrate, 4. Sliding plane.

Deposits caused by sliding (k) were formed as a consequence of the colluvial process, during which part of the eluvial-deluvial cover slide, and soil masses accumulated in the central and foot parts of the landslide. The lithological composition of the colluvial deposit consists of brown dusty clays with traces of underground water movement, concretions of organic material (semiliquid, easily squishy). The activated material in the sliding process is characterized by poor geotechnical characteristics and a higher degree of waterlogging due to the influence of underground and surface (atmospheric and waste) waters. According to GN-200, landslide belongs to category III and partly to category II.

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

Detailed engineering geological map (R 1:1000) was created after geomechanical tests and hydrogeological research. A geo referenced map on a scale of 1:1000 of the wider influential part [1,5,15] of the terrain was used as a basis for its creation, which was used for rezoning the terrain according to the degree of stability (Figure 4).

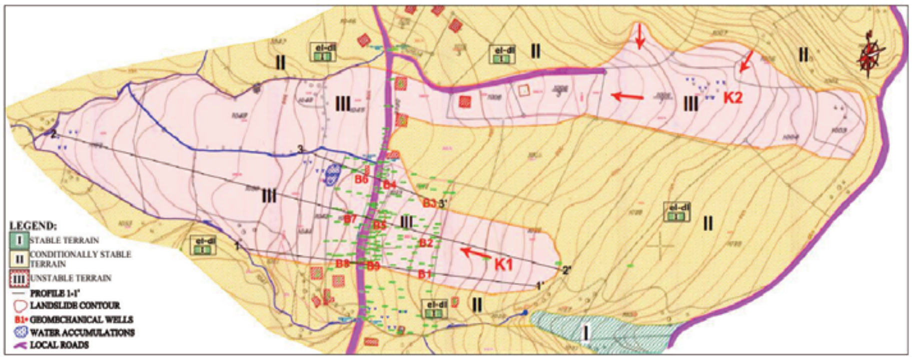

Figure 4. Land rezoning according to the degree of stability.

According to engineering geological mapping of the terrain according to the surface of the activated colluvial mass, the landslide in question belongs to a very large landslide. According to the type of process on the slope [6,7], the landslide is of a rotational type with an approximately circular cylindrical sliding surface, conditioned by different physical-mechanical properties and a simple movement mechanism. According to the volume of the sliding body, the landslide belongs to the large one. According to the morphology of the sliding body, it belongs to the amphitheatre type of landslide. According to the state of the activity it is reconciled. According to the structure of the slope and the position of the sliding surface, it belongs to the asequent landslide.

3. RESEARCH METHODS

For the purposes of defining geotechnical parameters, composition and properties of the terrain, the following research and tests were carried out:

- Geodetic surveys,
- Exploration drilling,
- Standard penetration tests,

- Laboratory tests,
- Analysis of slope stability,
- Engineering geological mapping,
- Rezoning of the terrain according to the degree of stability,
- Elaboration

As part of the geodetic survey, the situation was made in the national coordinate system on a scale of 1:500. The locations of the exploratory boreholes expressed in absolute coordinates were recorded.

As part of the exploration work, ten boreholes were drilled with a continuous standard penetration test along the entire depth of the borehole. The core was placed in appropriate boxes, mapped, determined and photographed. Disturbed and undisturbed samples were taken from completely fresh extracted core and properly preserved. Samples taken from the in-situ medium are taken at intervals in the borehole, so that all varieties of soil and rock encountered during the investigation are represented.

During the geomechanical testing, a hydrogeological observation of the phenomena of underground water acting in the soil was carried out.

Laboratory tests were performed in order to define the classification and physical mechanical characteristics of the soil [8], according to valid procedures in the accredited laboratory "GIT", Institute for Construction, Building Materials and Non-Metals, Tuzla: "BATA" accreditation is registered under number LI-04-01.

- Natural moisture is determined by the procedure: BAS ISO/TS 17892-1 Geotechnical investigations and tests - Laboratory soil testing - Part 1: Determination of moisture
- The volumetric mass of the soil is determined by the procedure: BAS ISO/TS 17892-2 Geotechnical investigations and tests - Laboratory testing of soil - Part 2: Determination of the 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.
- Atterberg's 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, under three vertical loads. The analysis serves to determine the parameters of shear strength, cohesion c (KNm^{-2}) and angle of internal friction ϕ (°). The test was carried out according to the provisions of BAS ISO/TS 17892-10 Geotechnical investigations and tests - Laboratory soil testing - Part 10: Direct shear test. Shear resistance parameters for the soil were determined in apparatuses for direct translation with a controlled deformation rate of dimensions 60 x 60 mm and a height of 25 mm. The samples were made in an undisturbed state and consolidated under vertical load σ': 50, 100, 150 KNm^{-2}, shear resistance ζ: 50, 100, 150 KNm^{-2}. Tangential stresses were increased in degrees $\Delta=\sigma'/40$ in time intervals $\Delta t1$ 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 corresponding intervals range from 5 to 9 KNm^2 for cohesion (c) and from 18 to 19° for the angle of internal friction (ϕ). Proper sampling provided representative values of material properties (for a given realistic case). For the calculation of slope stability, input geomechanical parameters that reflect the most unfavourable conditions on the slope were adopted.

The slope stability analysis was done with recorded terrain elevations, pore pressure coefficients for natural and drained slopes according to the Bishop method, on a licensed computer program of the Faculty of Mining, Geology and Civil Engineering from Tuzla. The method is based on the analysis of the equilibrium moment of a potentially unstable segment of the soil, for which the sliding surface is assumed to be a flat or cylindrical surface. The calculation is reduced to the determination of the safety factor against sliding (Fs), which is defined as the ratio of the moment of sliding resistance (Mo) and the moment of active forces (Ma) around the potential field of rotation of the sliding body.

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

Within the investigation area, the terrain was rezoned [9,10] according to the degree of stability with separate zones: stable, conditionally stable and unstable terrain, according to the area of representation (m^2) and percentage (%).

After the completion of the field work and laboratory tests, cabinet processing, analysis and interpretation of the collected data and obtained results were carried out with elaboration of the same.

4. RESULTS AND DISCUSSION

The paper presents the performed slope stability analysis for the 2-2′ profile with a length of 462.59 m and a slope of 5° to 12°. Through proper field and laboratory testing, representative samples that reflect the most unfavourable conditions prevailing on the slope were selected. For geotechnical calculation [1,11], geomechanical parameters are shown (Figure 5): volumetric weight, cohesion, tgϕ, pore pressure coefficient for each layer individually: 1) sliding mass, 2) cover and 3) geological substrate.

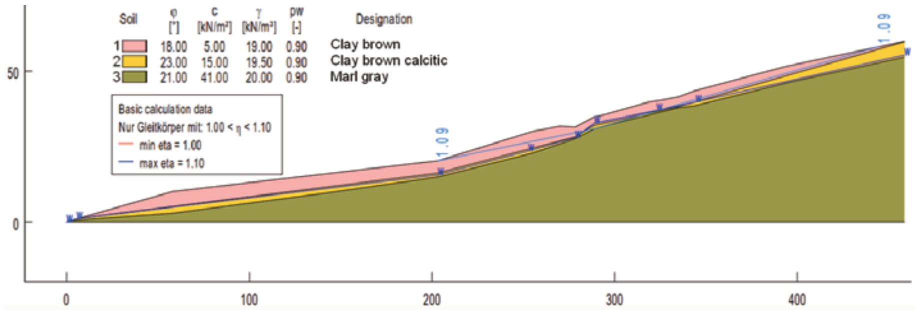

Figure 5. Model for stability analysis using the "Bishop" method, for the natural state (slope at the time of the survey).

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

On the analysed unstable slope, through the interaction of surface - precipitation, accumulated - stagnant and underground water, they adversely affect the reduction of normal effective stresses and thus the strength of the soil. Based on the established causes, sliding mechanism and vulnerability of the investigation area, the selection of the optimal method of stabilization of the traffic road in the length of 135 m as well as the immediately influential part of the unstable slope was performed [12]. By redistributing the masses, removing the excess soil material from the central part of the sliding body, installing stone material in the body of the road in the form of stone ribs (axial distance of 6.00 m) that will be supported by a layer of geological substrate, surface and deep drainage in the case of rotary sliding is reduced moment of the weight of the sliding body [13] with respect to the centre of rotation and thereby increases the safety factor (Figure 6).

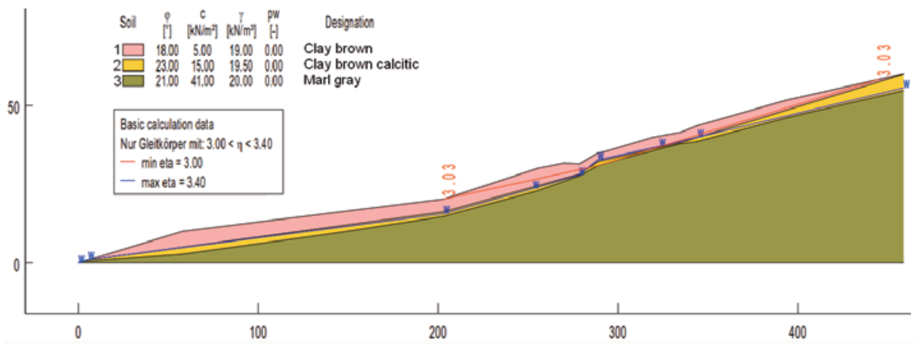

Figure 6. Model for stability analysis using the "Bishop" method (rehabilitated slope).

The safety factor with the specified measures of the rehabilitated slope is FS = 3.03 (stable). Landscaping, re-cultivation and drainage of the slope will ensure a reduction of pore pressure in the zone of the critical sliding surface.

After the rehabilitation is completed, it is necessary to establish instrumental monitoring [14] for a period of time of at least two hydrological years [15].

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

Unstable terrain

This terrain category represents a part of the explored area that is affected by the sliding process. The unstable part of the terrain occupies an area of 45,689.67 m^2, which represents 24.48% of the total area of the investigated slope of 186,677.30 m^2. The area of unstable terrain outside the investigated area is 23,881.48 m^2, which represents 12.79% of the total area of the endangered slope. In the unstable category of terrain, which is spatially clearly defined, no new construction or legalization of existing buildings can be carried out until detailed geotechnical investigations of the entire endangered area have been carried out. In this part of the terrain, it is not allowed to cut the terrain, as well as the formation of larger embankments.

Conditionally stable terrain

This category of terrain covers an area of 114,034.01 m^2, which is 61.09% of the total area of the terrain. With the prescribed measures and performed rehabilitation, it can be coverted into a stable terrain category.

Stable terrain

This category of terrain occupies an area of 3,063.14 m^2 or 1.64% of the total area of the investigated slope and is characterized by favourable geotechnical characteristics.

5. CONCLUSION

Based on the results of conducted engineering geological and geomechanical research, the established engineering geological and hydrogeological composition and properties of the terrain, the degree of representation of exogenous geological processes, the rezoning of the terrain according to the degree of stability, recommendations and conditions for the rehabilitation of unstable and conditionally stable terrain were given. Based on the rezoning of the terrain according to the degree of stability, it is possible to adapt the purpose of land use to geological conditions, which will certainly minimize material damage.

In this locality, the projected rehabilitation measures have not even started to date, although they have been marked as urgent due to the threat to material assets. Unfortunately, in most cases, the implementation of proposed rehabilitation measures depends on the available funds of the social community. Although landslides have become a problem that we encounter very often, not enough is being done on preventive measures to prevent new ones from appearing and to reactivate existing ones.

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

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