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ENGINEERING-GEOLOGICAL AND GEOTECHNICAL CHARACTERISTICS OF THE LANDSLIDE AT "CRVENE NJIVE" SITE IN TUZLA

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Summary

In the early morning hours of 05th December 2010, a small landslide was activated in the settlement of "Crvene Njive" in the MZ Mosnik, in the municipality of Tuzla. The activated landslide resulted in human casualties, major material damage and the collapse of an individual residential building located at the foot of a degraded slope, in which 3 people died. Two individual residential buildings were structurally severely damaged in the front part of the landslide. At the suggestion of experts, the population was assessed and temporarily evacuated from 12 endangered buildings. According to the existing geological and engineering-geological documentation, there was not registered any landslide or unstable slope at the micro-locality of "Crvene Njive" before the landslide was activated. At the location of the active landslide, there are several morphological forms of different hyposmetry levels, which were directly influenced by the geological structure of the terrain and human activity.
Based on the conducted geotechnical investigations, determined engineering geological and hydrogeological composition and properties of the terrain, the terrain was selected in zones according to the degree of stability, and important recommendations and conditions for the rehabilitation of the endangered area were presented.
Keywords: landslide, geotechnical investigations, landslide rehabilitation

INTRODUCTION

Due to the great impact on space, people and property, geohazard management is only possible through a systematic approach to study, cadastral data processing and by taking appropriate measures [1]. The record of landslide data in the Tuzla Basin area is very scarce, at a low level both professional and technical. The approach to landslide records in local communities in the Tuzla Canton area is also different. Previous experiences have shown attempts to record landslides using different forms for filling in landslide data, in which a significant amount of professional data is omitted, or the answers are very general, so that many are not relevant for further study, processing or integration into a database in digital form. In order to process cadastral landslide data and zone the area, it is necessary to have the results obtained from detailed geological, geomorphological, engineering geological, geomechanical, hydrological and hydrogeological surveys and tests. Namely, the engineering geological maps used as a basis for the spatial plan of the local community cover larger areas in the Tuzla Basin, and were prepared based on terrain reconnaissance, direct and indirect mapping. Such data are quite imprecise and do not provide a realistic picture of the terrain's vulnerability to landslides. Therefore, it is necessary to conduct detailed research to categorize the terrain as the terrain category conditions its use. With a deterministic approach, it is possible to reliably determine the degree of exposure to the risk of damage and endangerment of life. It is also necessary to prepare a cadastral list for other types of soil and rock material movements, such as landslides that have been recorded in the Tuzla Basin, and one such is presented in this paper. Based on the zoning of the terrain according to the degree of stability, it is possible to adjust the purpose of land use to geological conditions.

1. RESEARCH METHODS

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

- Geodetic surveys,
- Exploratory drilling,
- Standard penetration testing,
- Laboratory testing,
- Slope stability analysis,
- Engineering geological mapping,
- Geophysical testing of the terrain using the shallow seismic reflection method,
- Reionization of the terrain according to the degree of stability,
- Elaboration.

As part of the geodetic survey, a situation in the state coordinate system was made in a scale of 1: 500. The locations of the exploration boreholes were recorded in absolute coordinates.
Of the exploration works, two 15.00 m deep boreholes were drilled by a mechanical probe. The drilling of the MB-1 probe borehole was done without the injection of water and mud, and the MB-2 borehole was drilled with mud. The core was placed in appropriate boxes, mapped, determined and photographed by a geologist. The diameter of the boreholes in the cover materials is 101 mm, and in the geological substrate, a minimum of 86 mm. Disturbed and undisturbed samples were taken from a completely fresh extracted core and properly preserved. The samples were taken in-situ, i.e. in the medium, at intervals in the borehole, so that all varieties of soil and rock that occur during the research are represented. In addition to machine drilling, additional continuous penetration tests were performed to determine the compaction of the surface layer of sand that was poured into the landslide face during the first phase of rehabilitation and construction of the drainage system.
During the geomechanical testing, hydrogeological monitoring of groundwater phenomena present in the soil was carried out. Groundwater levels were measured 24 and 48 hours after the completion of the testing.
Laboratory tests were performed to define the classification and physical-mechanical characteristics of the soil [2], according to the current procedures in the accredited laboratory "GIT" Institute for Civil Engineering, Building Materials and Non-Metals Tuzla: "BATA" accreditation is registered under number LI-04-01. Natural humidity was determined by the procedure: BAS ISO/TS 17892-1 Geotechnical investigations and testing - Laboratory testing of soil - Part 1: Determination of humidity. Soil bulk density was determined by the procedure:

BAS ISO/TS 17892-2 Geotechnical investigations and testing - Laboratory testing of soil - Part 2: Determination of density of fine-grained materials. Specific gravity, at the prescribed temperature and humidity of the environment: determined by the procedure: BAS ISO/TS 17892-3. Atterberg consistency limits represent the yield point, plasticity and shrinkage limit, and were determined according to BAS ISO/TS 17892-12. The direct shear test was performed in a controlled shear deformation apparatus, under three vertical loads. The analysis serves to determine the parameters of shear strength, cohesion c (kNm^{-2}) and the angle of internal friction φ (^{o}). The test was performed according to the provisions of BAS ISO/TS 17892-10 Geotechnical investigation and testing - Laboratory soil testing - Part 10: Direct shear test. The shear resistance parameters for the soil were determined in a controlled rate translational direct deformation apparatus with dimensions of 60 x 60 mm and height of 25 mm. The samples were made in an undisturbed state and consolidated under vertical loads σ': 50, 100, 150 kN^{-2}, shear resistance ζ: 50, 100, 150 kNm^{-2}. The tangential stresses were increased in steps Δ=σ'/40 in time intervals Δt1 from 5 to 30 minutes. Shear rate is 0.3048 mm/min, dynamometer constant 0.034 mm/kp (0,33 mm/N). Obtained shear strength values and parameters c and φ obtained on soil samples for appropriate intervals range from 38 to 67 kNm^{-2} for cohesion (c) and from 22^{o} to 34^{o} 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 unfavorable conditions on the slope were adopted. Analysis and stability calculations were performed with recorded terrain elevations, computer records, using a licensed program and the Morgensteem-Price method. The method is based not only on the conditions of force balance along the x axis, but also the moment balance for each lamella. The analysis also allows for the search for the critical landslide surface. Based on the conducted research, tests and obtained results, a detailed engineering geological map was created in the scale of 1:500. The engineering geological map contains all relevant data for design and is prepared according to the Guidelines for the Preparation of Engineering Geological Maps (Guidelines of the International Association for Engineering Geology – IAEG) [3,4,5]. Within the research area, the terrain was sectioned 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 field work and laboratory tests, office data processing, analysis and interpretation of the collected data and obtained results were carried out with the elaboration of the same.

2. GEOLOGICAL COMPOSITION AND ENGINEERING-GEOLOGICAL CHARACTERISTICS OF THE TERRAIN

Part of the terrain in the zone of the activated landslide is located in the western part of Tuzla in the settlement of "Crvene Njive" [6]. The terrain is located at 44^{o} 31' 41.65" north latitude and 18^{o} 39' 17.79" east longitude according to Greenwich Mean Time. On this part of the terrain there was a wide ridge-like formation that had a general direction of extension southeast - northwest with a slope in the northwest direction of 10°. Because the mentioned ridge is mainly made of weakly bound quartz sandstone and clay, sandstone was exploited here for the purposes of backfilling the Moluhe mine until 1963. Due to the deficit of mass, a larger depression remained with two striking high (8-12 m) and subvertical slopes (west and south) with a slope of 80 to 90° (Figure 1).

Figure 1. Subvertical western slope. (Photo: J. Čomić, 2010).

After the exploitation of quartz sand was completed, the slope of the terrain was mitigated in the depression. Over time, part of the terrain in the southern slope zone became overgrown with low vegetation. Many buildings were illegally built in the hinterland of the southern slope about 20 years ago. The density of construction in the hinterland of the southern slope is very high, so some of the buildings were built on the sides of the ridge as well as near the high and steep southern slope. The buildings were 3 - 17 m away from the slope. The buildings did not have regulated drainage of rainwater and wastewater, and various materials were disposed of in the southern slope zone. Due to the high-altitude position, several buildings were connected to the water supply system from the direction of Krojčica, while the drains were directed towards the formed depression in the terrain.

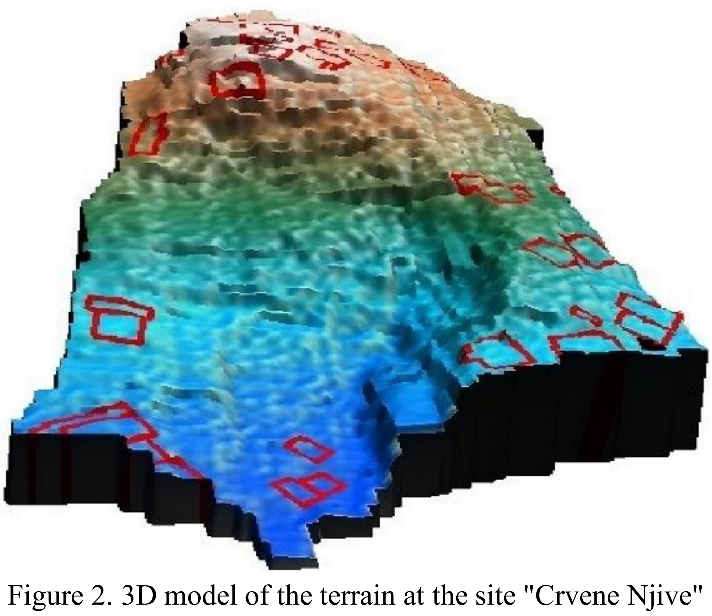

Figure 2. 3D model of the terrain at the site "Crvene Njive"

The average absolute elevation of the terrain in the hinterland of the southern slope was about

300.0 m.a.s.l., and at the foot, where the individual residential building was destroyed, 273.0 m.a.s.l. Figures 2 and 3 show models of terrain and buildings in the research area.

Figure 3. 3D model of buildings, digital terrain model and digital orthophoto plan (2021).

The research area is located on the northeastern side of the Northern Kreka Synclinorium. Pannonian sediments are represented by marls, clays, sands and sandstones with coal layers [7]. Previous research on coal seams has defined the hydrogeological relations of the area, according to the spatial distribution of individual lithological members, their mutual relationship, hydrogeological function and the relationship of individual collectors to surface waters [8]. In the wider area, aquifers can be distinguished by depth of occurrence: I aquifer (water bearing layer) sand in the bed of the bed coal seam - in deeper parts, II aquifer (water bearing layer) of weakly bonded sandstone in the bed of the main coal seam where the landslide was activated. These two aquifers are separated by overlying clays that represent a hydrogeological insulator. Increased flooding of quartz sands and weakly bonded sandstones have been determined by geophysical research.

In order to determine the engineering geological composition and properties of the terrain in the area where the landslide occurred, detailed engineering geological mapping of the terrain and geophysical research on three profiles were carried out. Mapping of open outcrops and high slopes was also carried out. On the ground, there are very high and open profiles where sandstones and clays were registered, and it was possible to measure the elements of the inclination of layers and cracks (Figure 4). The seismic method indicated the inclination depth of the lithological members and registered the spatial distribution of discontinuities in the sandstones.

Figure 4. Measurement of elements of the inclination of strata - western slope. (Photo A. Čomić, 2011)

During the engineering geological mapping of the terrain on the open outcrops of sandstone and interlayers of clay, elements of inclination 300/12° and 312/14° were determined. In addition to the measurement of the inclination elements of the layers, the measurement of the inclination of elements of the larger striking cracks in the area of the landslide scar was carried out (Figure 5).

Figure 5. Measurement of crack inclination elements in the landslide scar zone. (Photo A. Čomić, 2011).

Geophysical investigations (refraction seismic investigations using multiple interpretation methods) as well as field analyses defined discontinuities with elements of fracture inclination that are located deeper in sandstones and clays (on 3 geophysical profiles). In addition to the fractures, two faults (or deeper and wider fractures) were registered, extending in the east-west direction with the inclination of 85°. One fault was located in the landslide scar zone. The location where the landslide was formed is represented as a ridge that is composed of underlayer quartz sandstones of the main coal seam of the Northern Kreka synclinorium, where the layers incline in the northwest direction at an angle of 12^0 to 14^0 [9]. Quartz sandstone, according to its geotechnical properties, represents a conditionally stable terrain. However, stable terrain changes the stress state and becomes unstable due to inadequate anthropogenic works and activities, which happened at this location. Illegally constructed structures significantly loaded part of the terrain in the hinterland of the southern slope which led to additional changes in stress conditions. Only after geophysical investigations were conducted, it was determined that in the part of the formed landslide scar there was a fault with a narrow-weakened zone of similar orientation and inclination as the southern slope, which was the main cause of instability. After a period of relaxation of the stressed and naturally flooded material, a major separation and detachment of blocks (Figure 6) of sandstone occurred along the unfavorably oriented fault and neotectonics cracks, so that a classic landslide in sandstone with block detachment was formed.

Figure 6. Blocks of detached sandstone. (Photo by J. Čomić, 2011)

Due to the sudden separation of the sandstone mass along the fault, a larger block with a width of about 55 m and a length of about 17 m was torn off, which subsequently broke up into several smaller sandstone blocks of different shapes and volumes (from 1 to more m^3). Geophysical tests have determined that the depth of the landslide ranges from 10 - 12 m and is related to the depth of the clayey layer (substrate layer of the subfloor coal layer) located under the sandstone. Block tearing off and crushing was carried out along the lower order of cracks in the sandstone. As a subject is a semi-bonded and bonded material (sandstones), as a result of block tearing off along predisposed discontinuities, there was a sudden movement of sandstone blocks towards the foot of the slope where an individual residential building was located what resulted in casualties of 3 people. [10]

In the aim of rehabilitation of the southern slope, two 15.00 m deep boreholes were drilled by machine. The drilling of probe borehole MB-1 was done without the injection of water and mud, and borehole MB-2 was drilled with mud. In addition to machine drilling, additional continuous penetration tests were carried out to determine the compaction of the surface layer of sand that was poured into the landslide face during the first phase of rehabilitation and the construction of the drainage system. A geodetic base with a scale of R 1:500 was used to create the engineering geological map that was recorded in the national coordinate system. Based on the results of the research and testing, 3 engineering geological units were identified in this area, one of which belongs to the geological substrate, and two to the cover layers group.

Geological substrate

As a geological substrate recognized were one lithological type and one lithological complex were: weathered quartz sandstones (I), clays and calcitic clays with burnt fragments (II).

Weathered quartz sandstone (subfloor of coal layer I)

The color of quartz sandstones is primarily gray, and various shades of yellow also occur. They are characterized by satisfactory geotechnical properties. Stratification is registered on open profiles, clearly expressed in some places, and weaker in some parts. In the western slope zone between two layers of sandstone there is a thinner layer of clay (10 cm), which indicates a change in sedimentation conditions. In hydrogeological terms, weathered sandstones (partially consolidated quartz sands) represent hydrogeological collectors and a significant amount of groundwater is accumulated in them, especially in deeper parts. According to GN-200, weathered sandstones can be classified as category IV.

Clays and clays with burnt fragments - (coal seam overburden) (II)

At the site of the landslide "Crvene Njive", the overburden clays are located below a layer of weathered sandstone with visible outcrops in the flanks of the formed landslide. In the west of the landslide, a layer of clay with burnt fragments is located above a layer of weathered sandstone. The registered clays on the eastern flank of the landslide represent the overburden of the floor coal seam, and in the western flank the immediate overburden of the main coal seam. On the open outcrops of the overburden clays are gray-brown, well consolidated, with weakly expressed stratification. From a hydrogeological point of view, these materials represent insulators, and according to GN-200 they belong to category IV.

Covers

Two different genetic types can be distinguished in the cover group in the research area: eluvial-diluvial (ed) and colluvial (co) cover.

Eluvial-diluvial cover (ed)

This type of cover appears in zones where the striking reef has not been devastated by technogenic activity, in other words it is located outside the contours of the abandoned sand borrow pit. The lithological composition of this mixed slope cover is composed of yellow-brown dusty-sandy clays, varying in thickness from 0.5 to 1.5 m. In hydrogeological terms this cover has the role of a hydrogeological conductor, and according to GN-200 they belong to category III. Several buildings have foundation in this type of cover.

Colluvial cover (ko)

In the engineering-geological sense, the colluvial cover - the landslide consists of materials that were moved by gravitational movement, and which were accumulated in the lower parts of the slope. After the activation of the landslide, larger blocks of sandstone were torn off in the area of the former southern slope of the sand borrow pit, so that larger or smaller blocks of sandstone were accumulated in the lower part. This cover represents a degraded, cracked and loose environment of variable geotechnical characteristics. In certain landslide zones where large blocks of sandstone are separated, the primary stratification has been preserved. The thickness of the colluvial cover is variable and is shown on engineering geological profiles 1-1', 2-2' (Figures 7 and 8).

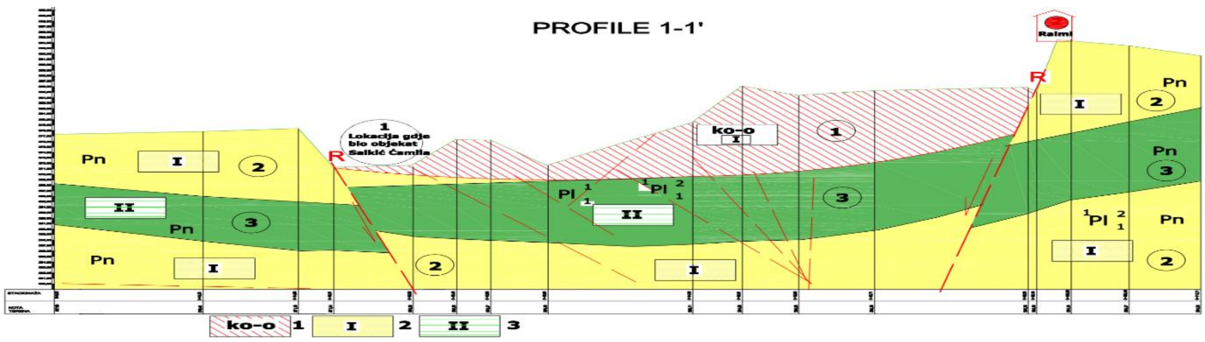

Figure 7. Engineering geological profile 1-1', southern slopes.

1. Landslide colluvium, 2. Soft quartz sandstones (bottom of the coal layer I), 3. Clays and clays with burnt fragments - (coal layer overburden) (II).

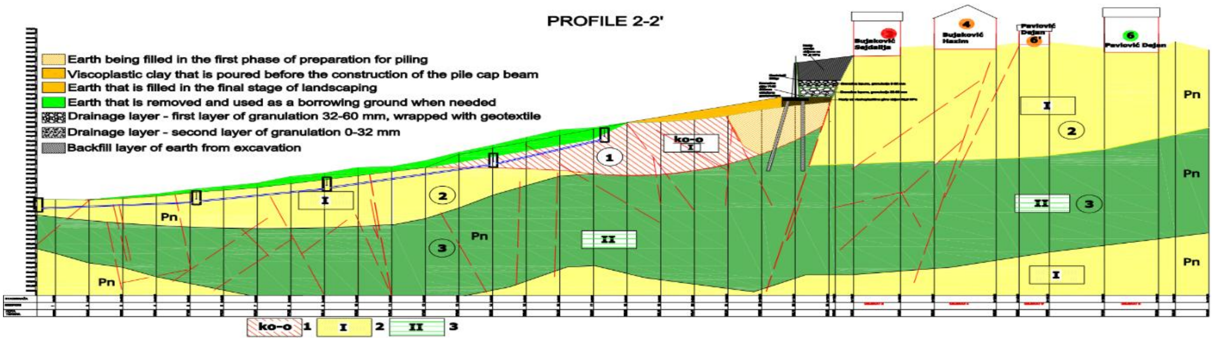

Figure 8. Engineering geological profile 2-2', with measures of the southern slope rehabilitation.

1. Landslide colluvium, 2. Soft quartz sandstones (floor of coal layer I), 3. Clays and clays with burnt fragments - (coal layer overburden) (II).

A detailed engineering geological map (R 1:500) was prepared after geomechanical and field investigations of the terrain, geophysical site investigations of the terrain using the refraction method and hydrogeological investigations. Within the research area, the terrain was regionalized [11] according to the degree of stability with separated zones: stable, conditionally stable and unstable terrain, according to the area of occurrence (m^2) and percentage (%). (Figure 9).

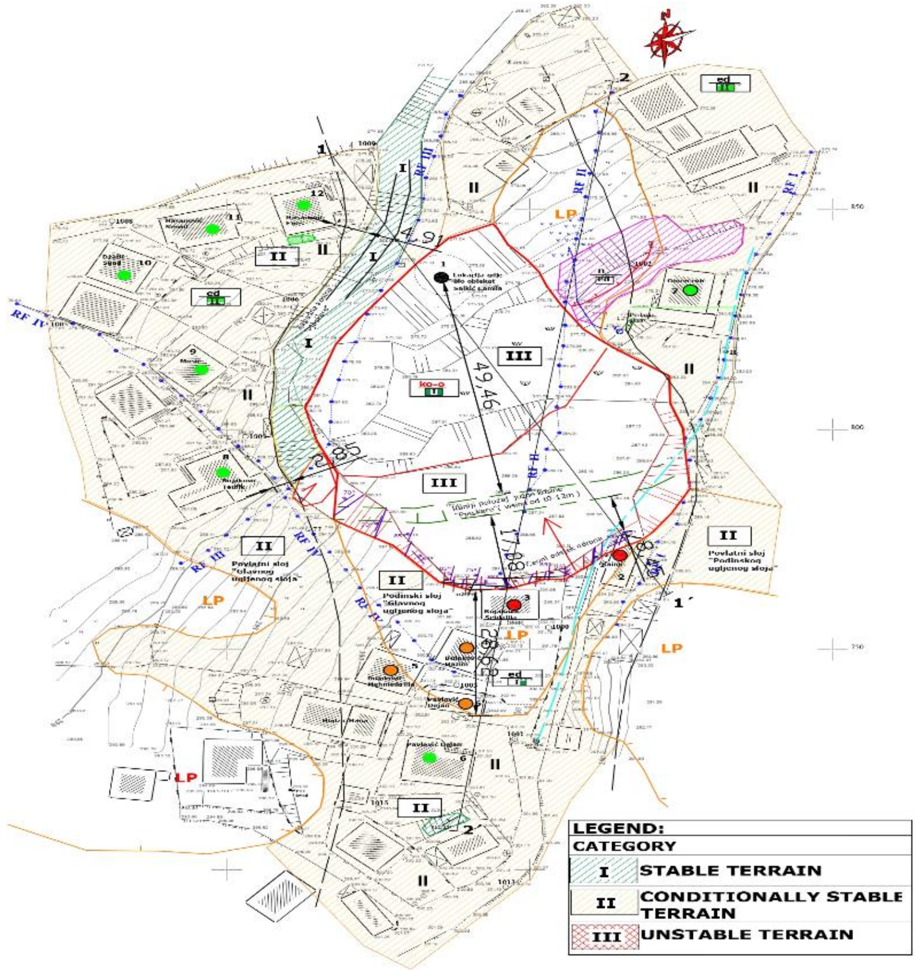

Figure 9. Terrain regionalization according to the degree of stability

2. RESULTS AND DISCUSION

The researched area is characterized by a distinguished interaction of natural factors (unfavorable orientation of cracks from the aspect of stability, hydrogeological conditions) and anthropogenic factors (decades of uncontrolled exploitation of sandstone, unplanned construction of buildings, unregulated drainage of rainwater and wastewater, illegal dumpsites, and inadequate and unprofessional implementation of rehabilitation measures at the first signs of instability. Based on the identified causes and vulnerability of the area with regard to (the possibility of landslide spread and further endangerment of residents and buildings), it is necessary to carry out a complete rehabilitation of the terrain, divided into two phases. At the beginning of March 2012, the first phase of the terrain rehabilitation was carried out by constructing a drainage system. The slope stability was increased by constructing a drainage system with the aim of draining flooded soil masses in the zone of flooded geological substrate, controlled drainage by drainage collectors. The first phase of the rehabilitation in the settlement also includes the recultivation of the terrain. The second phase of the rehabilitation is planned to include the construction of a supporting structure (reinforced concrete wall), based on reinforced concrete piers 10.00 m long, arranged in two axes according to the design of the supporting structure, supported in a layer of geological substrate. The safety factor of the repaired slope is FS=1.69 (Figure 10).

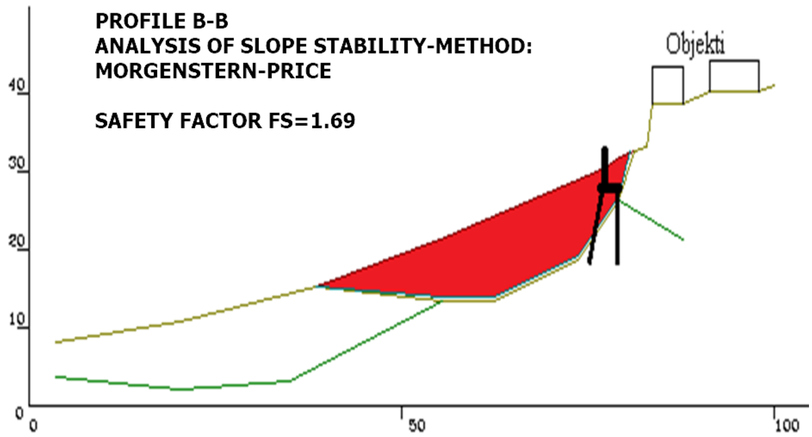

Figure 10. Model for stability analysis (repaired condition), profile B-B'.

After conducting research and zoning the terrain according to the degree of stability, a potential landslide propagation zone of about 28 m in length was defined in the hinterland of the frontal section, where many discontinuities in the sandstone massif were registered. All buildings and their residents located in this part where landslide propagation can be expected to be exposed to the risk of damage and endangerment of life. Ensuring the safety of facilities can only be achieved by implementing comprehensive rehabilitation. After the rehabilitation of the terrain is completed, geodetic monitoring is required [12].
On the engineering geological map (Figure 9), all three categories of terrain according to the degree of stability are spatially defined and marked:

Unstable terrain
This terrain category represents a part of the area affected by the landslide process. The unstable part of the terrain within the researched area occupies an area of 5,416.22 m^2, which represents 32.37% of the total area of the investigation area, which is 16,734.49 m^2. In the unstable terrain category, which is clearly defined in terms of space, no new construction or legalization of existing buildings can be carried out due to the possible reactivation of the landslide. Legalization of existing buildings cannot be carried out until the landslide has been completely rehabilitated, under expert supervision and monitoring of the success of the rehabilitation measures. In this part of the terrain any cutting of the terrain or the formation of larger embankments shall not be carried out.

Conditionally stable terrain
It occupies an area of 10,780.71 m^2, which makes up 64.42% of the total area of the researched area. With prescribed measures and performed rehabilitation, it can be transferred to the stable terrain category. Legalization of buildings can be carried out only after the rehabilitation of unstable terrain is completed. This terrain category can be transformed into the stable terrain category with prescribed measures.
Stable terrain
This zone belongs to the stable terrain category which is characterized by favorable geotechnical characteristics.
In the zone of the western slope or left side of the landslide with an area of 537.56 m^2, the

landslide is not expected to spread, but only to shed of the material, which should be prevented by protecting the slope from the effects of erosion.

CONCLUSION

Based on the results of the conducted engineering-geological and geomechanical research, the determined engineering-geological and hydrogeological composition and properties of the terrain, the degree of presence of exogenous geological processes, the zonning of the terrain according to the degree of stability, recommendations and conditions for the methods of rehabilitation of unstable and conditionally stable terrain are given. Based on the zonning 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. With a deterministic approach, it is possible to reliably determine the degree of exposure to the risk of damage and endangerment of life.
At the Crvene Njive site, before the landslide was activated, the edge of the southern slope was 17 m. Three people lost their lives when the landslide was activated in December 2010. The estimated value of 12 residential buildings located in the immediate vicinity of the landslide is almost one million convertible marks.
After detailed research and testing on the southern part of the slope (where many discontinuities in the sandstone massif have been registered), a tendency for further landslide expansion and destabilization of the southern slope by another 26.68 m is expected. This would endanger 4 more individual buildings and the people living in them. These buildings are located in a high-risk zone, and their estimated material damage is around 320,000 KM. Calculated price of the rehabilitation of phases I and II (drainage and protection of the southern slope with a supporting structure) is around 470,000 KM. By conducting a site visit and comparing geodetic bases in vector and raster form (during the research and new ones), it can be concluded that more than a decade has passed, and that the designed rehabilitation measures (except for the implementation of the first phase) at the Crvene Njive site have not been implemented, although they were marked as urgent.

LITERATURE

[1] Čomić, J. Upravljanje geohazardima na području tuzlanskog basena. Univerzitet u Tuzli, Doktorska disertacija, 2022.
[2] "GIT" Institut za građevinarstvo građevinske materijale i nemetale Tuzla, 2011.
[3] Varnes, D.J. Slope movement types and processes. Landslide analysis and control. Transportation Research Board, Special report 176. (ur. Schuster, R.L., Krizek R.J.), National Academy Sciences, Washington, DC. 11–33, 1978.
[4] Varnes DJ, IAEG Commission on Landslides and other Mass-Movements Landslide hazard zonation: a review of principles and practice. The UNESCO Press, Paris, 63, 1984.
[5] Cruden, D.M., Varnes, D.J. Landslide types and processes. In: Turner, A.K., Schuster, R.L. (eds): Landslides investigation and mitigation, Transportation Research Board, US National Research Council, Special Report 247, Washington, DC, Chapter 3. 36-75, 1996.
[6] Čomić, J. Elaborat o inženjerskogeološkim i geomehaničkim ispitivanjima za Idejni

projekat sanacije odrona u ulici R. Meškovića i B. Ajdžajlića u naselju "Crvene Njive" u Tuzli. Glavni projekat sanacije odrona u ulici R. Meškovića i B. Ajdžalića u naselju "Crvene Njive" MZ Mosnik – općina Tuzla, 2011.
[7] Vrabac, S. Paleogeografija južnog oboda panonskog basena u badenu i sarmatu. Doktorska disertacija. Rudarsko-geološki fakultet Tuzla, 1989.
[8] Čomić, J. Hidrogeološki i antropogeni uslovi formiranja i stabilizacije klizišta na lokalitetima u Tuzli. Univerzitet u Tuzli, Magistarski rad, 2012.
[9] Soklić, I. Postanak i struktura tuzlanskog bazena. Geološki glasnik br.10, 1964.
[10] Kantonalna uprava civilne zaštite. Procjena ugroženosti od prirodnih i drugih nesreća područja Tuzlanskog kantona, 2016.
[11] Sijerčić, I. Inženjerska geodinamika, Univerzitet u Tuzli, 2012.
[12] Mihalić Arbanas, S., Arbanas, Ž., Krkač, M. TXT-tool 2.385-1.2 A comprehensive landslide monitoring system: The Kostanjek landslide, Croatia, In: Sassa K. et al. (eds): ICL Landslide Teaching Tool, ICL, Kyoto, Japan, 2013.