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MODELS OF CONTEPMPORARY GEODYNAMIC PROCESSES ON THE RIM OF THE SARAJEVO DEPRESSION

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SUMMARY

The rim of the Sarajevo depression was exposed to a strong construction expansion, which was not followed by spatial planning documentation. This work presents models of modern geodynamic processes, which are mainly caused by technogenic effects. The characteristics of these processes mainly depend on the morphological properties of the terrain, geological structure, engineering geological and hydrogeological properties, as well as technogenic factors. The aim of this work is to clarify the specificities of modern geodynamic processes in the areas of different lithological formations, and also to show their classification and special treatment considering process's dynamic, the development method of the moving rock mass, causes of its movement; all with the goal of preventing or reclaiming the negative effects of these processes. The key factors that affect modern geodynamic processes are: terrain morphology, lithological structure, groundwater level, rock mass structure, as well as the technogenic processes.

Key words: *modern geodynamic processes, landslips, landslides, Sarajevo depression.*

INTRODUCTION

The problems of landslides, as well as other modern geodynamic processes, have been present since ancient times, with the fact that sudden urbanization and the construction of high-rise buildings and road infrastructure led to their significant activation. The first steps in solving and studying this issue on the territory of the former state were taken by professor M.T. Luković [1,2].

„Landslide is a complex slope process of movement, usually of disintegrated and weakly bound rock masses, along a clearly expressed shear surface, which is called a sliding surface. Part of the rock masses that, due to various factors, move by shearing down the slope, without separating from the ground, is called a landslide, i.e. the body of a landslide.“ [3].

The basic question that is posed to the experts is: how to forecast the tendency of the terrain to appear unstable [4] explained that matter in great detail and for practical purposes. According to Professor J. Perić [5] the most widespread is the lithological criterion, that is, defining geological environments“ [3]. This criterion is the basis of this work.

Engineering geological research in the area of the city of Sarajevo and its surroundings began after the World War II, and intensified to a significant extent, with the sudden urbanization and construction of the city of Sarajevo. Numerous investigative works were carried out, for individual structures, with the aim of defining the engineering-geological properties of the rock masses from which the terrains were built, on which future construction objects will be based, whether they are road infrastructure objects or high-rise buildings.

RESEARCH METHODOLOGY

During the research of the terrain, that is, unstable slopes around the edge of the Sarajevo depression, the most modern methods were applied, both in the field and in laboratory conditions. Based on these results, their synthesis was performed and characteristic types of instability were isolated.

A number of shallow boreholes, exploratory cuts and exploratory pits were carried out, certain geophysical investigations were also applied, as well as a significant number of laboratory geomechanical, mineralogical and petrological tests, as well as a numerous engineering geological and hydrogeological maps have been created for specific areas of Sarajevo and its surroundings, all aimed at defining the conditions for the construction of certain structures or addressing the stability conditions of specific slopes, including already activated landslides.

During the 1970s and 1980s, extensive regional geological research was carried out, the final result of which was the „List Sarajevo, OGK SFRJ“. With this paper, all doubts about the age of individual lithological formations, their position in the geological column, and the physical-mechanical properties of individual lithological members, their hydrogeological properties and function in a broader sense were defined to a significant extent.

RESEARCH RESULTS

The geomorphological characteristics of the terrain and its rezoning

In view of the expressed very large height differences both in the area of the city of Sarajevo itself and in the area of its wider surroundings, we can single out two more significant regions in a general sense:

- The area of the mountain rim (Mountain region), where several different levels can be distinguished, which have special lithological, hydrogeological, structural and hydrological properties;
- The flattened area together with the depression of the Sarajevo field (Quaternary Sediment Area), where there are mainly Quaternary sediments on the surface, whose engineering-geological and hydrogeological properties are precisely dependent on the thickness of these sediments.

High mountainous area

It is an area with an altitude of more than 1000 m and includes all the surrounding mountains which are interconnected and almost completely enclose the Sarajevo basin (Igman-Bjelašnica-Trebević-Jahorina-Crepoljsko, etc.). Only in Bjelašnica can we state larger amounts of denudation-glacial origin, while the erosion process (karst) takes place mainly in the inner part of the rock massif in the form of chemical disintegration of the rock mass.

Middle mountainous region

The area, which in terms of geomorphology is significantly more complex and covers an area of 700 m above sea level. up to 1000 m above sea level On the northern slopes of Trebević, Jahorina, Romanija, and on the southwestern slopes of Crepoljsko, we can see isolated and large massive limestone blocks of the Anisian layer T_2^1, which lie in a concordant relationship over the Verfen sandstones (Sarajevo

sandstones) T_1. It is at the contact of these two lithological units that numerous larger or smaller wellsprings appear (Vrelo Bosne, Vrelo Miljacke).

Lowland belt

In morphological terms, this area significantly differs from the previous ones, as in addition to the Middle Triassic limestones and dolomites, as well as the Verfen sandstones, Tertiary and Quaternary sediments are present, represented by terraces (river and lake), occasionally with deluvial sediments, as well as fossilized alluvial fans.

Sarajevo field depression

From the morphological aspect, it is a terrain that has gentle, sometimes steep slopes around the edges of Sarajevo itself (at the contact with the previous morphological unit), up to a completely leveled area in the area of Sarajevo Field. The slopes are covered usually with a thin deluvial cover, in some places we can see smaller-sized sinkholes, while the Sarajevo field depression itself is built of fluvial (Quaternary) sediments of the rivers Bosna and Miljacka, which are somewhat thinner around the edges, while they are significantly thicker along the river courses themselves. In the area of Čengić Vila, the thickness of fluvial sediments is about 2 meters, while their thickness increases significantly towards the open area of Sarajevsko field. Fluvial sediments are represented by alluvial terraces (alluvium), then dominantly by the gravel fraction, as well as by occurrences of lenses of sand, clay and silt. For this area, the engineering-geological properties of the terrain depend to a significant extent on the level of groundwater oscillation.

From the aspect of this paper, and with the aim of defining the engineering-geological properties of the terrain, which are important for the construction of buildings and infrastructure in Sarajevo itself, the low-lying areas and the area of the Sarajevo field depression are important to us.

Geological structure of the terrain

The geological structure of the terrain of the city of Sarajevo and its wider surroundings can be classified into four geological units, namely:

a. Lower Triassic or Verfan sediments (T_1), in which we distinguish three lithological units:
   - A complex of sandstones, marls and clays, where from a geotechnical point of view we can state that this series represents an unfavorable working environment, especially if the structural position is unfavorable in relation to the slope. In terms of hydrogeological function, this lithological series represents a hydrogeological insulator. In the geological past, it was exposed to strong tectonic processes and strong influences of exogenous factors, primarily the denudation process. (Sedrenik, northern slopes of Trebević, Pale, Mošćanica). From the engineering-geological aspect, it can be classified as rocks with unfavorable properties, where the terrain is conditionally stable on slightly inclined slopes, while on steep slopes it is conditionally stable to unstable.
   - The complex of layered white and red sandstones (colorful Sarajevo sandstones), which are more favorable than the preceding lithostratigraphic unit from an engineering-geological point of view, and the slopes built from these sediments are stable to conditionally stable (Trebević, Sedrenik, Hreša, Pale, Mokro).
   - The complex of marls and thin-layered marly limestones is less widespread and can be found in the area of Kijevo, as well as in places on the northern slopes of Trebević. According to their engineering-geological properties, they are similar to pure limestone rocks.

b. Complex of limestone and dolomitic limestone of the Middle Triassic ($T_2^{1,2}$)
   - Massive limestones of the Anisian floor of the Middle Triassic (T_2^1) they build the lowest parts of the rim of the Sarajevo depression, they are characterized by a high degree of cracking, large systems of cracks along which shearing and tearing of large blocks occurred along the rim. As

a working environment, they are very favorable, these rocks can be used as a quality building material, while the natural slopes are stable.

- Bedded to stratified limestones of the Anisian and Ladinian stages of the Middle Triassic, characterized by a high degree of karstification, significant presence of fractures in larger dimension fissures. Alluvial fans have formed at the bases of these rock sections, natural slopes are stable, and these rocks are less commonly used as construction materials due to the presence of chert.
- Layered thin-plate limestones and marls of the Ladina layer, significantly twisted and folded, natural slopes are conditionally stable to unstable. They are rarely used as building material.
- Volcanic sedimentation complex of the Ladin layer, where in addition to thin-plate limestones with cherts and marls, rocks of volcanic origin include tuffs and spilites. Depending on whether they were discovered or not, then on the structure of the rock mass, they behave differently according to erosion-denudation processes.
- The first three formations in the hydrogeological sense function as conducting collectors, while the last formation functions as an insulator.

c. Jurassic-Cretaceous J,K (Tithonian-Valendian) flysch

This lithostratigraphic unit is represented by breccias, breccia limestones, marls and clays that alternate in the geological column, and each of the individual facies of this complex has its own engineering geological and hydrogeological properties. In general, we cannot observe them individually but as a complex, and conclude that this complex has different engineering-geological, geotechnical and hydrogeological characteristics that depend on the individual facies of this flysch complex. In places, this lithological formation functions as a hydrogeological collector, and in places as an insulator. It is spread around the perimeter of the Sarajevo depression and is isolated in the localities of Hreša, Ljubna, Koševski potok, Zujevina, Rakovica and some other localities.

d. Tertiary complex of multifacies freshwater sediments

This complex of freshwater sediments in engineering geological terms is very colorful, depending on which facies is dominant. In the area of the Sarajevo depression and its rim, three series are distinguished:

- A series of conglomerates, sandstones with thin layers of marl occurs in the area of Sedrenik, Vrace, Lukavica and Kasindol. This series is characterized by a general dip towards the Sarajevo field (west-southwest), so the stability of the slopes essentially depends on the orientation of the interlayer surfaces as well as the cracks that cross them.
- Facies of weakly bound sandstones developed along the stretch from Podhrastovi—Veliki Park—Mejtaš—Hambaina carina. They have a distinct collector function, which is of crucial importance for the stability of slopes.
- A series of thin-layered marls, sandstones and clays (Koševska series) make up the area of Koševski potok, Čengić vila, Lukavica, Kobilje glave. The lithification process is not complete, i.e. these rocks in places change to their unbound equivalents, and this series can be characterized as unfavorable in terms of engineering geology. In the hydrogeological sense, different types of outcrops were formed in this formation.

e. Quaternary cover, represented on the slopes by mostly thin, less often thicker deluvial cover, then by sipar, and by alluvial sediments along the river courses, of different thicknesses.

Contemporary geodynamic processes on the edge of the Sarajevo

Landslides can be found practically in all geological formations in our country: from the oldest to the most recent [2]. Contemporary geodynamic processes, which take place along the perimeter of the Sarajevo depression, were previously caused by the physical-mechanical disintegration of primary rock masses which, under the influence of certain factors, then moved down the slope, and then in recent geological history, the consolidation and binding of these rock masses took place.

This is how a primarily deluvial cover was formed, which can be of significant thickness in places. This deluvial cover represents a relatively "suitable" environment for the formation of landslides, that is, for the detachment and uncontrolled movement of this mass down the slope if certain assumptions have been made beforehand (gravitational conditions, water saturation of the terrain, disturbance of the primary geostatic conditions in the terrain, etc.). Landslides are most common in Tertiary sediments, followed by Flysch Jurassic-Cretaceous (J,K), while contemporary geodynamic processes in the Triassic are represented by landslides, landslides and seeps, as accumulative forms.

a. Landslides in Triassic sediments (T_1, T_2^1)

These landslides were formed on the steep slopes of Triassic limestones, in the bottom of which lie white and red (Sarajevo) sandstones. Previously, on the slopes, sluices of significant dimensions were formed, partially cemented with clayey material. In natural conditions, these slopes are relatively stable, while in the process of building road infrastructure, as well as high-rise buildings, and during the exploitation phase of roadways, there was an occurrence of instability and the activation of sliding and sliding processes (Lapišnica landslides, landslides on the road from Hreša to Sumbulovac, as well as landslides on the northern slope of Trebević, the Vraca–Brus road), as shown in Figure 1. Uncontrolled dumping of soil and other waste material on a naturally unstable slope, in the area of Lapišnica, led to the occurrence of landslides of enormous proportions.

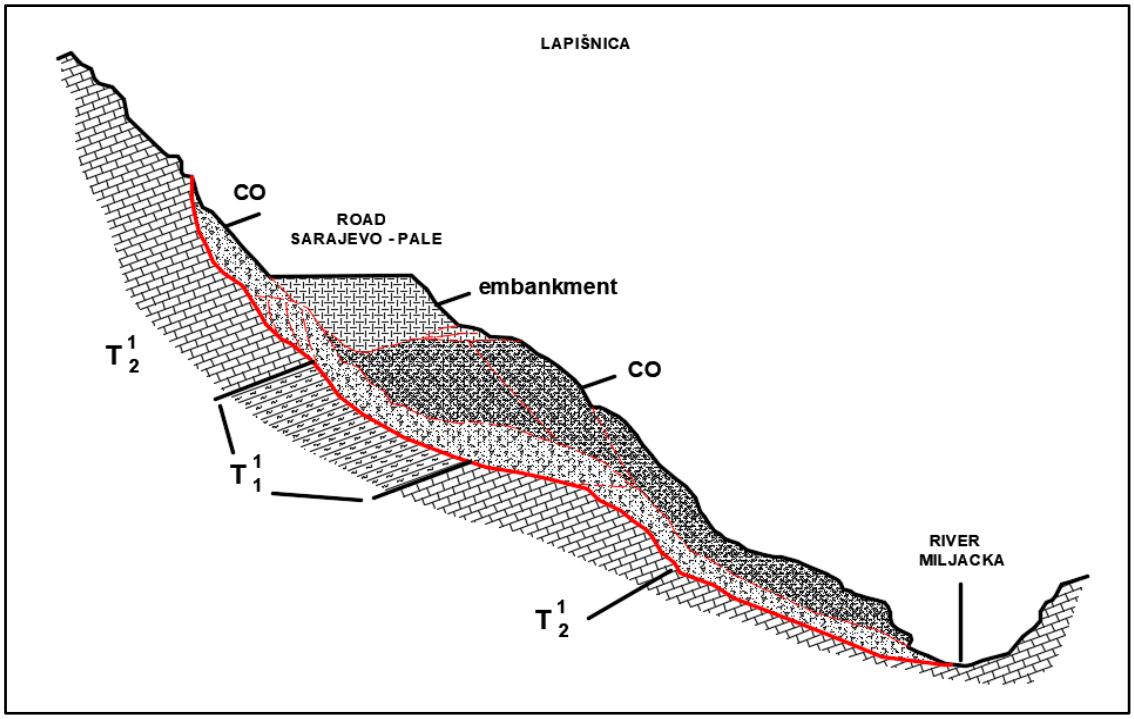

Figure 1. Lapišnica landslide

At the level of the road, an embankment several tens of meters thick was formed in order to create a leveled plateau, on which the construction of the building was planned. Backfilling was carried out over the colluvial cover on the steep terrain, which is located on the Middle Triassic, heavily crushed limestones, and in the deeper parts of the terrain, below them is the Lower Tiacian sandstone-clay complex.

As a result of the heavy load from the filled mass and the large amount of water, both surface and underground, the slope was moved and the road was washed away on a length of 170 meters. The moved earth mass also threatened the bed of the river Miljacka, and there was an objective danger of the formation of a dam and a lake in the upstream part.

„The occurrence of the Lapišnica landslide was predisposed by the heterogeneous geological structure of the terrain (in complex spatial relationships), and the impact of the newly formed landfill in conjunction with specific hydrological and hydrogeological conditions was decisive for the loss of balance and radical displacement of the terrain on 19-20.11. 1999“ [6].

b. Landslides in Jurassic-Cretaceous flysch (J,K)

In the higher parts of the terrain, there is a flysch polyfacies complex built of: marls, calcarenites, sandstones and clays, and in the lower parts, the middle Miocene complex, represented by marls, sandstones and clays, and clays with carbonaceous interlayers, lies transgressively and discordantly over it. The flysch complex is intensively harvested, tectonically deformed, blocky and superficially decomposed, and the Miocene sediments are weakly diagenetically consolidated and subject to relatively rapid changes [7,8]. In the flysch complex, decomposition products are gravitationally moved towards the lower parts of the terrain, creating colluvial deep curtains as shown in Figure 2. These are slow, shallow to deep landslides. The causes of landslides are related to the natural morphogenetic development of slopes, surface and underground water, as well as technogenic activity.

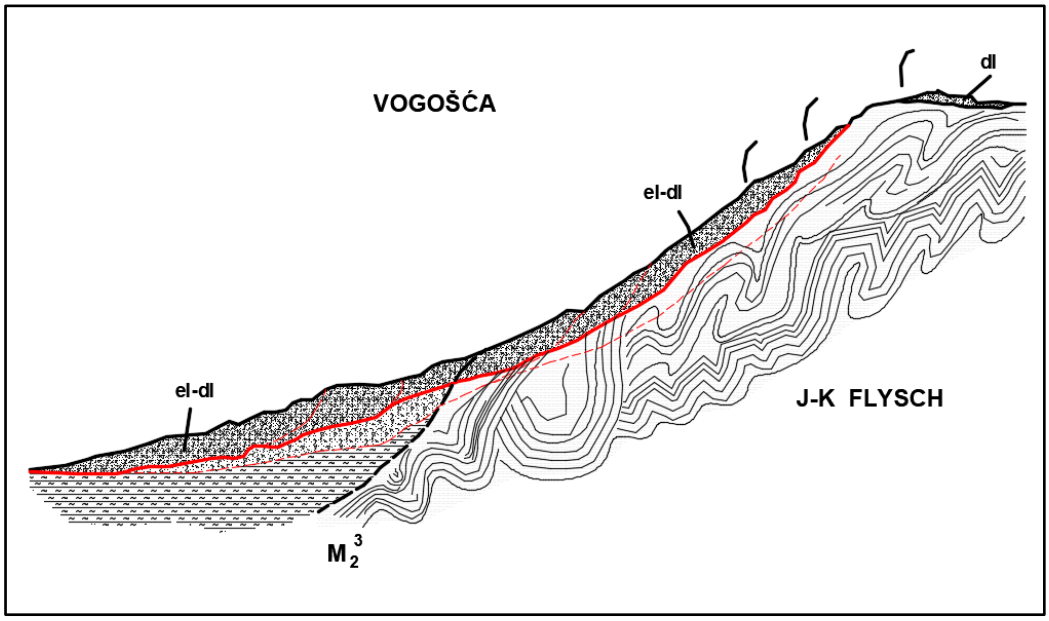

Figure 2. Landslide in the flysch complex

c. Landslides in the tertiary complex (Tc)

Landslides that are formed in the geological substrate of tertiary deposits where there is a different thickness of the decaying crust, then different lithological composition and different hydrogeological properties. In this lithological complex, landslides are formed according to the stated conditions, the position of the Quaternary sediments on the slope, the water saturation of the terrain, the disturbed natural geostatic condition in the terrain, the "favorable" position of the structure of the tertiary sediments for the formation of the sliding surface. In the area of Koševski potok and Sušica potok, a large number of smaller landslides were formed due to the disturbance of the primary geostatic condition in the terrain, and a typical representative of this type of landslide is the Crni Vrh landslide, which is shown in Figure 3.

The Crni Vrh landslide is not unique, but because of its specific the structure of the substrate is actually divided into three landslides [7]. The lithological complex of tertiary sediments does not have an extremely unfavorable structural orientation and the landslides were formed in the first phase at the substrate-cover contact, so that in the further phase of landslide development, the substrate would also be partially affected.

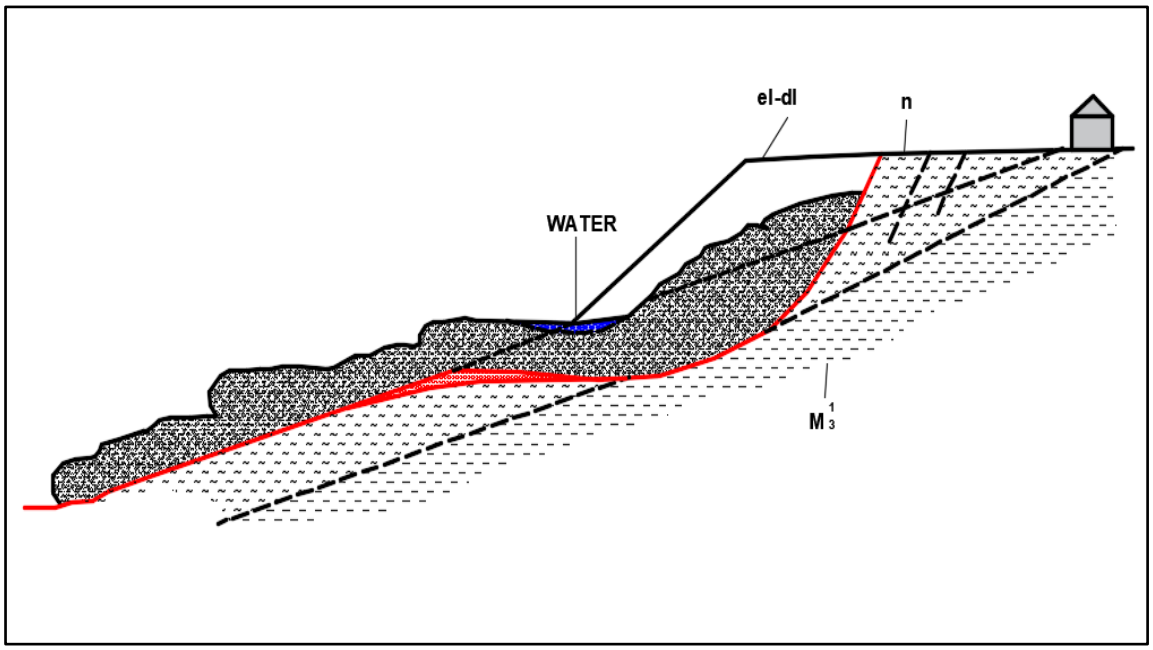

Figure 3. Landslide Crni Vrh

Deformations, i.e. the slope process of moving the mass takes place in this way, partly where the orientation of the structure of this lithological formation allows, they are also transferred to the substrate, i.e. the base rock. In the sloping parts of the city, landslides of this type are very common and are found on high embankments next to the streets, on local garbage dumps, etc. According to the activity of the sliding process, these are relatively fast landslides that require urgent interventions to prevent their further uncontrolled spread.

d. The slope in the Pofalići-Velešići area is built of Upper Miocene sediments (M_3^1) the so-called "Koševo series" of marls, marly clays, clays, sands and marls shown in Figure 4. The complex is layered with the position of the structure down the slope, which further worsens the stability of the slope in natural conditions. The inclination of the slope varies from 15^0 to 30^o.

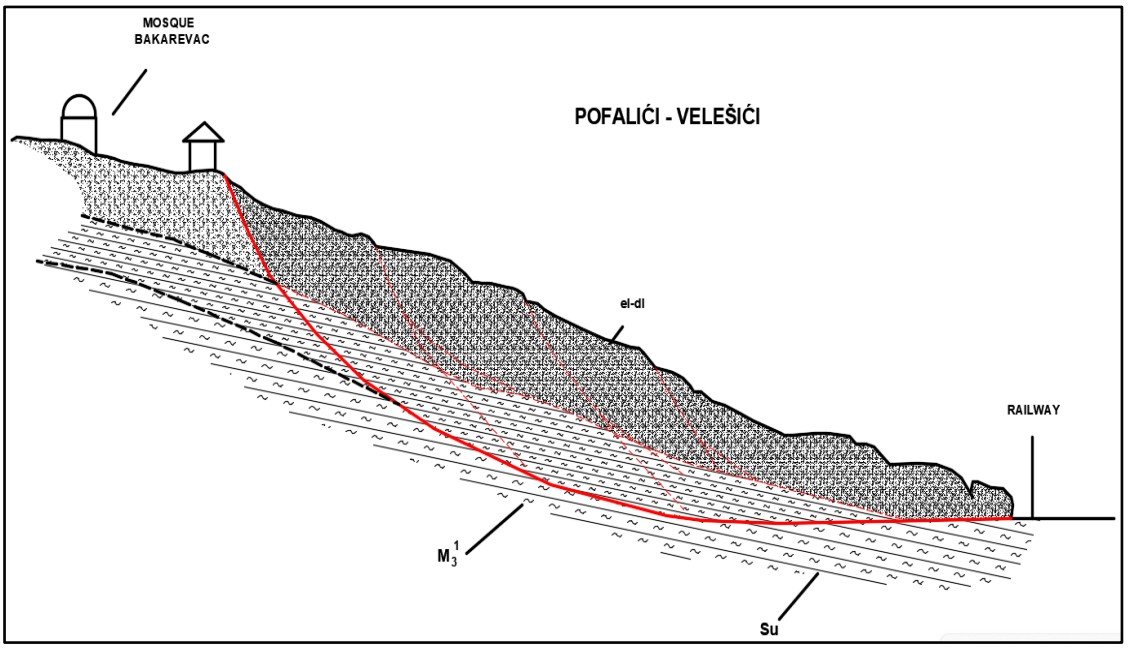

Figure 4. Landslide Pofalići - Velešići

The initial movements of instability occurred at the foot of the slope, so that the process of mass movement down the slope would successively spread towards hypsometrically higher parts. In addition to the natural predisposition of the terrain, additional man-made human activities, primarily the illegal construction of buildings, there was a significant activation of the movement of the rock mass down the slope.

e. Quaternary landslides (Q)

Landslides in the Quaternary were formed as a result of gravitational movements of rock masses, mainly in a loose cover as shown in Figure 5. These landslides are connected to the sources of streams and rivers on the edge of the Sarajevo depression and are located at high elevations, and in the lowest parts of the basin where streams flow into larger watercourses (mainly in plavine fans). The slope is built of eluvial deluvial cover in the surface part of the terrain and Neogene sediments, the so-called Koševo series.

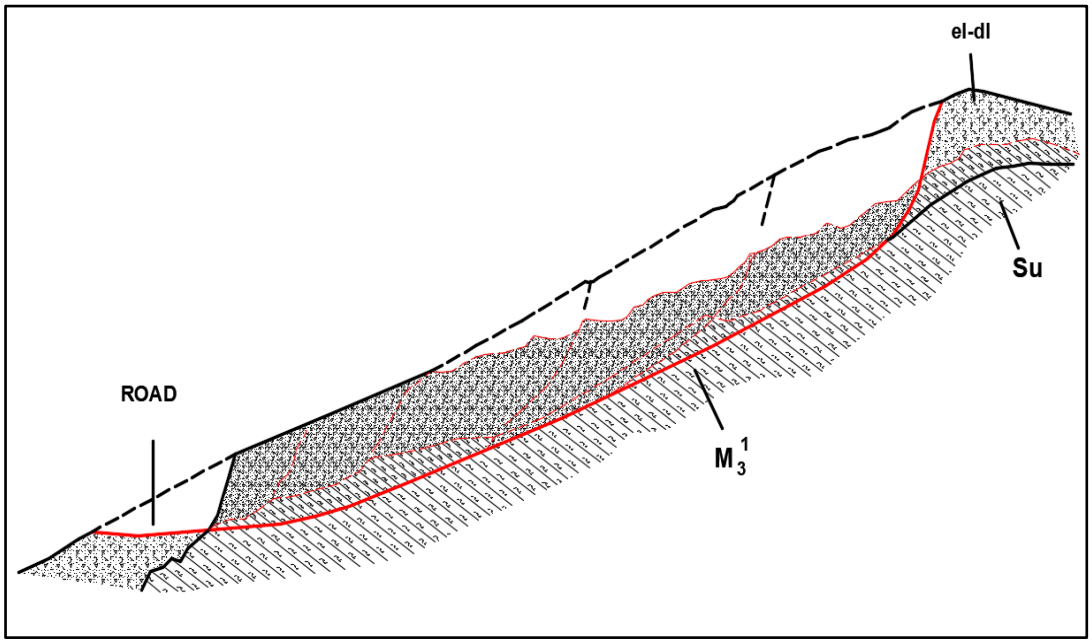

Figure 5. Landslides in quaternary formations

In the case of inadequate cutting of the base of the slope, when making frontal excavations for linear objects or foundations of stable objects, the initial movements occur immediately behind the formation of the cut, and then the sliding process spreads successively towards the hypsometric parts of the terrain until local equilibrium is established.

THE RESULTS ANALYSIS

In this paper, five characteristic types of landslides are presented, with clearly defined conditions of their occurrence. The causes of the occurrence, i.e. activation of the sliding process, can be reduced to: geological, geomorphological, physical and technogenic.

The geological conditions for the occurrence of landslides are found in the rock masses themselves, in the manner and conditions of their formation, physical-mechanical properties that reflect their ability to react faster or slower to all external agents of destruction.

Geomorphic conditions are related to the morphogenetic development of slopes, i.e., the shaping of the terrain under the influence of contemporary exogenous processes.

Physical or climatic conditions are related to the amount of precipitation, sudden freezing and melting of snow.

Technogenic activity or human activity is the most common cause of landslide activation. These landslides, in addition to their frequent occurrence, are characterized by rapid and uncontrolled processes, which often have serious consequences for residential and infrastructure facilities.

CONCLUSION

The area of the Sarajevo depression abounds with numerous occurrences of landslides and rockfalls, primarily due to the geological structure of the terrain as well as their very complex tectonic structure.

The basic geological environments that favor the formation of landslides are limestones in a morphologically scattered relief, which lie over Verfen sediments, then Neogene sediments, flysch sediments and the Quaternary cover.

The area surrounding the Sarajevo Depression has been exposed to strong construction expansion for the past 40 years, mainly the construction of individual buildings, then the construction of the infrastructure that had to accompany the construction of these buildings (road, water and sewerage, electricity lines, etc.). There are very few areas where there was spatial planning documentation, i.e. illegal construction is present to the greatest extent, which was almost nowhere followed by geological surveys, assessments of the stability of cut slopes, assessments of the bearing capacity of the terrain when building foundations, etc.

Thanks to the extremely thin decomposition crust (in places we also have a somewhat thicker decomposition crust), then the favorable orientation of the rock mass structures, the lithological structure of the substrate, during the execution and construction of these constructions, the investors did not face any significant problems, which required expensive rehabilitation (the exception is landslide Lapišnica).

The paper presents models of contemporary gliding processes that took place along the peripheral parts of the Sarajevo depression, mostly initiated by technogenic processes, i.e. human work. In places, there are several smaller landslides right next to each other, but essentially they do not represent a single whole, primarily due to the position of the rock mass structure in relation to the terrain surface (Crni Vrh landslide).

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