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LANDSLIDES ON MOUNT TREBEVIĆ SLOPES – ANALYSIS OF THE RESEARCH RESULTS

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ABSTRACT
Landslides on mount trebević slopes – analysis of the research results
The study area is located on the northwestern slopes of Mount Trebević, in a densely populated area. Based on previous research at slope parts of Trebević, three complex with large-scale landslides wereidentified (landslide of Hambina Carina, landslide of Mrakuša and Trebevićka Street landslide-expanding complex) and there were observed also landslides of Soukbunar and Jewish cemetery. By the research conducted during 2014, drilling of exploratory wells was carried out, as well as engineering-geological and geotechnical investigations and laboratory testing of samples of soil and rocks that are a continuation of earlier started researches. By the research, there has been collected enough data to create a study on engineering-geological and geotechnical characteristics of the terrain and for the purposes of the regulatory plan (RP) "Soukbunar". After realization of the planned work, it was approached to drawing up of elaborate and database for objects.

KEY WORDS
landslides, engineering-geological research, geotechnical research, laboratory testing, regulatory plan, categorization of the terrain, monitoring.

1. Introduction

According to the Institute for Construction of Canton Sarajevo, by 2009 in Sarajevo Canton, around 755 landslides were registered. After the disaster in May 2014, the number of landslides has increased to 1100. The largest number of registered landslides is in Vogošća, Novi Grad, and the Center and Old Town. Exploration so far at slopes of Trebević to the city of Sarajevo ascertained three complex large-scale landslides (landslide Hambina Carina, landslide Mrakuša, and Trebevićka Street landslide - expanding complex) and were observed also landslides of Soukbunar and Jewish cemetery. By the program of investigation works, it was planned a detailed engineering geological mapping, shooting angles and coordinates of investigation works, performing exploration wells, control when performing investigative work, recording core drilling, sampling soil from boreholes, laboratory testing of soil samples.

During 2014 engineering-geological and geotechnical research were carried out, as well as performed exploratory wells and laboratory testing of samples of soil and rocks that are a continuation of earlier started researches. By these observations, there was conducted the terrain categorization according to the degree of stability and benefits for construction, and data was collected for preparation of the Study on engineering geological and geotechnical characteristics of the terrain and the regulatory plan "Soukbunar". The research found that the thickness of the surface coverings is very different and on average higher than programmed, as well as that, under the blanket there is a geological substrate decay crust very variable and uneven geomechanical characteristics. The study also found that the solid undisturbed geological substrate in some wells is located at much greater depths. Based on engineering geological mapping and the results of exploratory wells and laboratory testing, the terrain categorization was performed according to the degree of stability and benefits for the construction. After finalization of the planned works, it was approached to drawing up of elaborate and database for objects.

2. Geographical location of the study area

The study area is located on the slopes of Mount Trebević, in a densely populated area on the sloping part of the town. The exploration area covers an area of approximately 84 ha and administratively belongs to the Municipality of Center. The position of the study area is shown in Figure 1., and it stretches from the rocky cliffs and plateaus on Trebević in the south, to the street Put Mladih Muslimana (city bypass) in the north. The western border includes Jewish cemetery and crossing the Počiteljska and Trebevićka Street it extends to Vranjače.

The eastern boundary extends along a nameless stream until the first transverse west streets coming from the street Žagrići, by which it continues in the direction of the street Žagrići and then to crossroad with Hambina Carina.

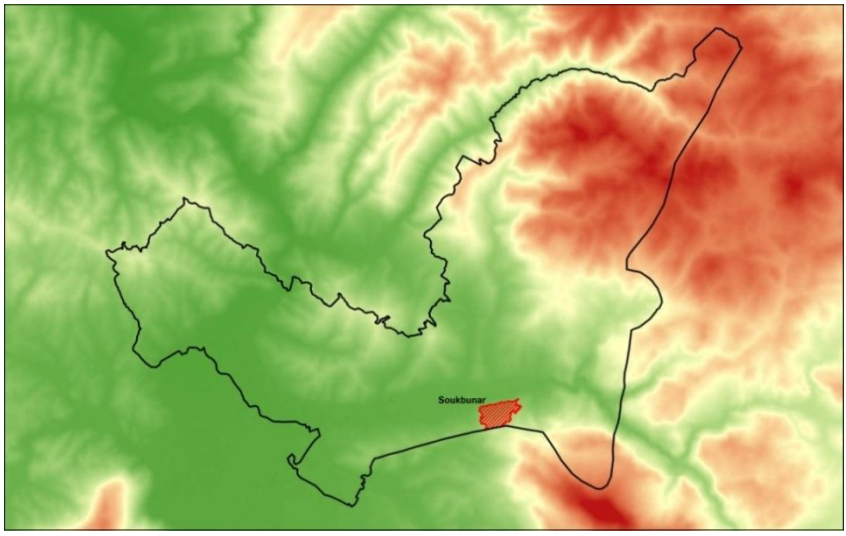

Figure 1: Location of study area (Soukbunar) within City of Sarajevo

3. Geological and tectonic structure of the terrain

The observed area belongs to the structural-facial units "Crepoljsko – Trebević – Treskavica – Prača" and "Sarajevo-Zenica Neogene basin". The study area was built of layers of Lower Triassic (T_1), Middle Triassic limestones (T_2^1), Neogene sediments of Upper Miocene ($^1M_3$) and modern Quaternary sediments (Q), in the form of surface cover. Some geological formations have complex facial structure and complex tectonic structure so this reflects the qualitative and quantitative characteristics of rock masses and their stability at slope parts.

Lower Triassic (T_1) is presented with white (quartz) and quartz-mica sandstones, slates, aleurolites and marls and less with limestone marls.
Medium Triassic age (T_2^1) are limestones of Anisian floor, karstified, tectonic degraded and block divided by fracture discontinuities.
Upper Miocene sediments ($^1M_3$) of Sarajevo-Zenica Neogene basin so called "Koševo series"are situated transgressive and discordantly over Anisian limestones and poly-facial complex of Verfene.
Quaternary products (Q) are made of elluvial-delluvial geological substrate decomposition products, colluvial materials of screes, avalanches, landslides and mudslides, and anthropogenic embankment materials.

According to the Main geological map sheet Sarajevo, tectonic structure of the observed and surrounding area belongs to structurally facial units "Crepoljsko – Trebević – Treskavica – Prača" and "Sarajevo-Zenica Neogene basin". Mount Trebević is a huge overturned anticline, whichis block divided by regional and local faults in smaller tectonic blocks, with a series of overthrust (small coverings) especially in the northeast and south-western slopes. Tectonic unitof Trebević was pulled over geologically younger clastic flysch sediments of Jurassic and Cretaceous and in general, it sinks towards Sarajevo under Neogene Sarajevo-Zenica basin. Major faults in this area are fault in the direction of Mahmutovac – Toka – Trebevićka Street – Zlatište (parallel to the visible cut off) and two smaller reverse refractive structures in the direction of Toka – Kneginjac and Čeka – Čolina Kapa.

4. Geomorphological Characteristics of the Terrain

The observed terrain of the RP "Soukbunar" area belongs to the hilly and mountainous relief type, with elevations of 570-593 m above sea level in the north of the street Put Mladih Muslimana ("Bypass"), up to altitude 675 m in the south, at Cicin Han, i.e. 699 m above sea level at Trebevićka, and all up to 777 m above sea level. The heterogeneous geological structure, neotectonic activity and the different behavior of rock masses in the surface decomposition zone influenced the complexity of the geomorphological terrain structure. In terms of morphogenetic,several types of relief were isolated: erosive-denudate, gravitational-accumulative and karst-erosive type of relief.

Erosive-denudate terrain is made of poly-facial complex of Upper Miocene and Lower Triassic and has a dominant character.
Gravitational-accumulative terrain is presented on the slopes of Mount Trebević beneath steep limestone cliffs.
Karst-erosive terrain takes higher parts of the terrain on Mount Trebević. It was built of Middle Triassic limestones.

The slope of the terrain surface is important in spatial planning, construction of buildings and roads, water and sewage networks, and utilities and other facilities on the territory of the regulatory plan "Soukbunar". According to the slope of the terrain, the categorization was made as follows – optimal favorable terrain with gradients of up to 5%, favorable terrain with slopes 5-10% and conditionally favorable terrain with gradients of 10-20% (not considered in the study area). Unfavorable terrain with a slope of more than 20% occupies the entire surface of the field for 84.23 ha (Table 1).

Table 1: Construction suitability according to terrain slopes

	Favourableness degree	**Slope inclination** (%)
I	Optimally favourable terrain	1 – 5
II	Favourable terrain	5 – 10
III	Conditionally favourable terrain	10 – 20
IV	Unfavourable terrain	> 20

5. Engineering geological and hydrogeological characteristics of the terrain

Engineering geological categorization and classification are based on lithogenetic criteria and on research of the terrain as well as on knowledge of the relationships between the engineering properties and lithogenetic characteristics of isolated rock masses as the basic mapped units.According to the degree of homogeneity, rock masses are classified into one (1) lithological type (LT) and 7 (seven) lithological complexes (LC) as basic taxonometricunits. According to the degree of diagenesis and strength of connections between minerals and mineral aggregates, taxonometric units are classified into two main groups: bound and unbound (quaternary blankets) and hard and soft rocks (geological substrate).

Surface (quaternary) blankets were originated by processes of the geological substrate decomposition or by anthropogenic activity during the construction of roads and buildings. Based on Genesis, separated are types (horizons) of surface cover: anthropogenic (technogenic) blanket, colluvial cover and elluvial-delluvial cover.

Anthropogenic blanket lies over colluvial and elluvial-delluvial products in the construction of roads and around the individual objects in a form of the embankment. It is made of asphalt, concrete, limestone scree, gravel, grit, sand and a mixture of sandy clay, rubble and less gravel. The thickness of the cladding ranges from 0.2 to 3.3 m.

Colluvial cover lies under anthropogenic and over elluvial-delluvial cover. It occupies approximately 24.08% of the observed terrain. Its thickness varies from 2.4 to 34.7 m.

Elluvial-delluvial cover occupies approximately 70.21% of the study area and lies beneath the anthropogenic and colluvial materials, and over geological substrate. Humus, multicolored dusty and sandy clay, fine-grained sands, fine-grained debris sandstone, shales and siltstones, marl and clay present it.

This cover is a favorable environment for the formation of landslides, and contact with a geological substrate represents a critical discontinuity to generate the sliding processes. Exploration drilling for the purpose of RP "Soukbunar", and previous studies, revealed a thickness of elluvial-delluvial cover from 0.2 to 21.0 m.

Geological substrate lies in deeper parts of the ground beneath the surface cover, or is in the form of bare surface outcrops.

Featured are two levels of substrate: crust of the geological substrate's decomposition and geological substrate. Geological substrate decomposition crust lies directly over the rock masses of geological substrate and it represents product of decomposition of basic rocks under the influence of weathering and infiltration waters. Due to significant differences in lithological composition, state and properties of individual lithological complexes and types, there were selected: sediments' decomposition crust of Upper Miocene and sediments' decomposition crust of Lower Triassic - Verfene.

The geological substrate is presented with three lithostratigraphic members – clastic sediments "Koševo series' of Upper Miocene ($^1M_3$), carbonate deposits of Middle Triassic (T_21) and clastic sediments of Lower Triassic – Verfene.

Given that the basis of geological terrain was built of soft rock masses and, that land cover (ground) are inwards and silty-sandy clay, the subject field, according to geological structure for the construction of settlements, can be considered optimally suitable and affordable for the construction ingeological substrate. As fordecomposition crust of Verfene and Upper Miocene, and colluvial materials and elluvial-delluvial cover, it can be considered suitable and conditionally favorable terrain, or terrain with smaller and larger restrictions that can be technically solved.

Hydrogeological characteristics of the terrain in the area of RP "Soukbunar" are very complex thanks to geological structure of the terrain, the structure of porosity and permeability of rock massesin general. In the study area, according to the water permeability and hydrogeological features they have, selectedare porous rocks with the function of hydrogeological collectors and impermeable rocks with the function of hydrogeological insulator.

Permeable rocks towards the porosity structure can berocks with intergranular porosity and rocks with fracture-karst porosity. Permeable rocks with intergranular porosity are unrelated or crumbly colluvial (kl) and elluvial-delluvial deposits (el-d), and anthropogenic materials (n). Colluvium materials are presented with mid-permeable and elluvial-delluvial with anthropogenic materials that are poorly water-permeable rocks.

Permeable rocks with fracture-karst porosity are banked to massive limestones Middle Triassic – Anisian (T_2^1). Limestone have been discovered in the southern parts of the terrain and are good karstified rocks, which can be classified in the class of medium and good permeability.

Impermeable rocks that have the function of hydrogeological barrier, are rocks of the 'Koševo series' of Upper Miocene ($^1M_3$) and sediments of Lower Triassic -Verfene (T^1).

During the conduction of investigation works on the ground, the groundwater are found at different depths, mainly in elluvial-delluvial and colluvial blanket. According to the depth to groundwater' level, the observed terrain can be classified as conditionally favorable and favorable terrain.

6. Condition of landslides

On the subject area ascertained are three complex landslides with large scale such are landslide Hambina Carina, landslide Mrakuša and Trebevićka Street landslide- wider complex that are repaired.

Landslide "Hambina Carina" extends from the Cicin Han street to the foot of the limestone cliffs of Trebević in the "Osmice" area and between the streets of Hambina Carina and Mrakuša. At this landslide was designed and built a complete system of remedial measures. In the very south part, below the street of Hambina Carina, there is a part of a landslide that extends all the way to the "Osmice". Landslide is active and not explored.

Landslide "Mrakuša" is a continuation of the landslide "Hambina Carina" area of 15.5 hectares. Allocated were five prominent i.e. large private sliding units (HP-1 HP-5), and with them, seven individual small sliding bodies. Landslide is of complex type and now it is mitigated (Figure 2).

Landslide "Trebevićka Street – wider complex" is a mitigated complex large-scale landslide, that covers significant pat of the study area.

Landslide on the upper side of the Trebevićka street (landslide KT-1)where the partial mitigation was on, because when stopping motion directly above the road, that certainly could contribute to the stability of the lower parts of the slopes and buildings.

Figure 2: Drainage system and caution board about active landslide in the lower part of Mrakuša locality

Figure 3: Mitigated escarpment and caution board in the Trebevićka Street

Landslide between the Trebevićka and Kasindolska Street (landslide KT-2)has been repaired and now is in the state of inaction.

Landslides between the streets of Pećina and Urijan Dedo (landslide KT-3) do not show the status of activities and probably they are in the state of differentially - plastic flow - soil creep.

Landslide "Trebevićka Street – wider complex" where the performance of remedial measures and work were done in four basic phases.

Figure 4: Caution board about active landslide in Trebevićka Street – wider complex

Besides the aforementioned complex landslides, on the subject area were allocated and repaired "Soukbunar" and "Jewish cemetery"landslides.

Landslide "Soukbunar" is located directly along the right (east) side of the Trebevićka Street - wider complex landslide. Performing remedial measures and work on the landslide is mainly related to the mitigation and construction of water and sewage network, and with a small part, to the construction of retaining structures.

Figure 5: Wall cracks in the streets of Porodica Foht and Soukbunar (Soukbunar landslide)

Landslide "Jewish cemetery"is located in the area of Jewish cemetery. The mitigation of the landslide was carried out by building of the drainage system and concrete channels for surface drainage.

Figure 6: Jewish cemetery landslide

Current activities are focused on the establishment of monitoring for observation of all mitigated landslides, the only one that can provide quality information on the effects of remedial measures, and the degree of their mobility (active, temporarily calmed, inactive). It is of great importance for further development plans in this part of the city of Sarajevo, and the creation of RP "Soukbunar".

7. The Stability of the Terrain and its Categorization According to Construction Suitability

Based on engineering geological mapping and the results of exploratory wells and laboratory testing, terrain's categorization has been performed according to degree of stability: a stable, relatively stable and unstable terrain (Figure 7).

Stable terrainis part of the terrain built of rock substrate masses presented with Anisian limestones. Stable parts of the terrain occupy an area of 14.55 ha, or 17.32% of the study area.
Conditionally stable terrainare part of the hillsides made of embankment materials, colluvial and elluvial-delluvial cover that are, in natural conditions, of stable weight, but in terms of cuts and additional burden can become unstable. Conditionally stable parts of the terrain occupy the largest surface of 42.54 ha, or 50.47% of the study area.

Unstable terrain are courts with active landslides, avalanches and rock creeps. Unstable parts of the field covers an area of 27.14 ha, or 32.21% of the study area.The categorization of the terrain according to construction suitability, in addition to geological structure, the slope of the terrain, hydrogeological and geotechnical properties, and field seismicity, represents a summary assessment, and evenly important are climatic conditions, economic, social, traffic and other factors. Together they form the basis for reaching the final assessment on the benefits for the existing settlements expansion.Standard categorization of the terrain according to construction suitabilityhas been done in five categories: very favorable terrains for construction; courts are favorable for construction; courts conditionally favorable for construction; courts unfavorable for building and grounds extremely unfavorable for construction.
Terrain that is very favorable for construction are not found in the area.

Lands favorable for construction are made of Anisian limestones and they are without landslides and avalanches. Within this category, the terrain has no significant limitations for dense construction of small individual and large residential buildings, but for larger objects, it is necessary to implement adequate engineering geological and geotechnical investigations. On the subject area, they cover the space of 14.55 ha. In terrains suitable for the construction has no significant restrictions, except that, before the construction of roads along the route, to exam capacity and subsidence in areas of terrain with thin Quaternary cover. For such terrain, because of unfavorable morphology due to slopes with inclines even over 10^{o}, it is to be reckoned that the implementation of roads requires significant earthworks, which adversely affect the cost of construction.

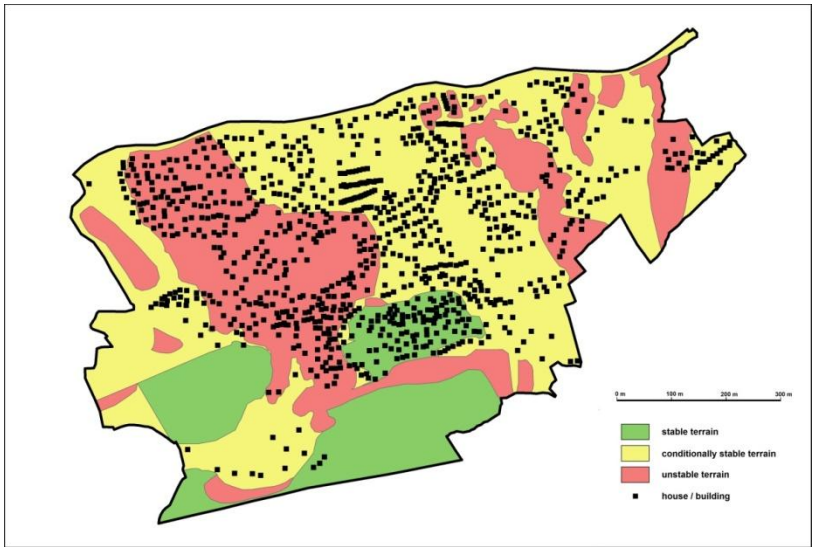

Figure 7: Terrain stability map of Soukbunar

Terrain conditionally (limited) suitable for construction is also present in Soukbunar locality and covers the biggest share of its total area. In case of relatively shallow geological substrate with favorable settling layers, there is a good basis to build all kinds of buildings on the ground. However, in cases of thick blankets and unfavorable geological settling layers of geological substrate during the construction works (undercut, cutting, filling, inadequate drainage) there is a possibility of eroding existing stability, as well as the formation of landslides. These fields occupy the largest area of the field in amount of 42.54 ha, or 50.5% of the total area of the field.Within the conditionally favorable terrains for the construction, exterior landscaping and implementation of roads should be such that cutting and filling on slopes are to be as less as possible. On these grounds in the construction of roads, one should avoid filling and depositing material on the slopes, but in case of a necessary formation, surface embankments should be pre-arranged. Generally,it can be said for these areas that there has no need for special measures of remediation of large scale, but that the construction itself should be planned and executed so that the conditions of stability on slopes improve.

Within the **unfavorable terrains for construction** (Category 4), one should strive to carry out mitigation of the unstable terrain through the very building, so building construction facilities contribute significantly to the stability of slope. There is a need to avoid building on the grounds of these categories, but in case it must be built, it is necessary to plan the construction of a higher intensity because only such construction can bear the costs of remediation field. If building construction of the courts in this category is inevitable, in planning construction one should comply with all the conditions that are set for conditionally favorable terrain (Category 3), provided that these conditions are set here in much sharper form. In context of unfavorable terrains, if construction of roads must be carried out, one should comply with all the conditions that are set for the conditional favorable terrain, provided that these conditions are set here in much sharper form.

In ***extremely unfavorable terrains,*** construction of roads is not recommended. In case of a specific need for construction, mitigation of landslides and unstable parts of the field should be calculated prior to a road construction. When building roads in this category of the terrain there is a possibility that inadequate construction can lead to further expansion of existing active landslides, avalanches and rock creeps. In extremely unfavorable parts of the ground for construction (Category 5), construction of new buildings is not recommended. Possibly building on these areas, it could be implemented on condition of carrying out detailed geological and geotechnical explorations at the site. Lands extremely unfavorable for construction occupy smaller area of 3.43 hectares, which amounts to 4.07% of the total area of the field.

8. Seismic Characteristics

Study area, as well as the wider area of Sarajevo by M. Vidović (1974) belongs to the so-called Dinaric neotectonical area and, neotectonic zone with Middle-Bosnian valleys and is located in the epicentral area of Treskavica-Sarajevo. This area covers a space of approximately 1,000 km^2, with a maximum of registered intensity VIII° MCS scale. It comprises the area between Kalinovik and Trnovo, and most of the mountain Treskavica. Immediate epicentral area is located on Mount Treskavica, along dislocations that inversely separates Triassic carbonates of flysch formations.

According to manifestations of seismic events and epicentral zones, area Treskavica-Sarajevo is divided into two unstable areas. First is the area north of Kalinovik in domain of mountain Treskavica an area of 124 km^2 with the intensity of VII° MCS. Eight earthquakes in total were registered, of which one in 1962, with the intensity VIII° MCS, was strongly felt in the city of Sarajevo.The second area is located along the axis of Trnovo-Sarajevo-Vogošća. Part of the area became part of the Sarajevo-Zenica Basin. Stirs up with its own earthquakes with epicenters near Sarajevo, where so far were registered at least 32 earthquakes, and earthquakes from unstable Treskavica zone. The frequency of earthquakes is one at 25-50 years, the intensity of about VII° MCS.The enclosed map clearly shows that the basic level of seismicity of Sarajevo and the subject investigated terrain is 7° MCS.

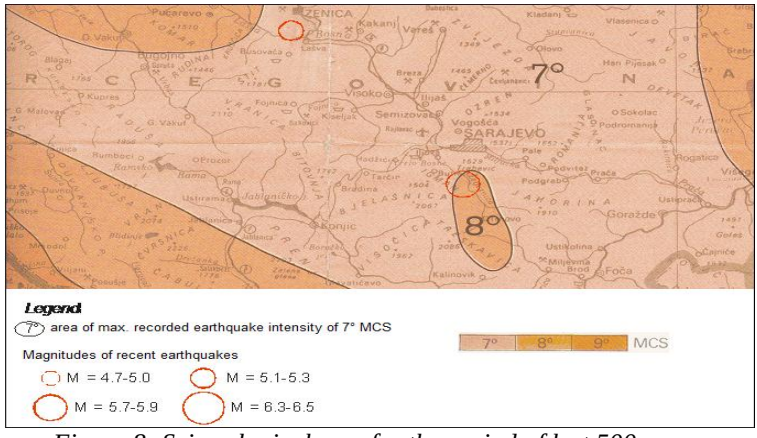

Figure 8: Seismological map for the period of last 500 years

To define seismicity of certain micro location in the subject field, it is necessary to have a more detailed knowledge of soil stability, water level and others, but this requires additional testing. To correct the basic level of terrain seismicity practically can be used the table of S.V. Medvedev:

Table 2: Correction of basic seismic degree (according to Medvedev)

Seismic terrain categories	Bedrock types	Seismic degree		
		7	8	9
		Seismic determination		
I	a) Solid rocks: granite, limestone, sandstone etc. b) Semi-cohesive sediments: marlstone, clay sandstone etc. c) Unconsolidated sediments: debris, gravel, sand with depth of underground water of more than 15 meters	(-1) 6	(-1) 7	(-1) 8
II	a) Dry clay rocks b) Sand and clay with the depth of underground water of more than 8 meters c) Gravel and debris with the depth of underground water between 6 and 10 meters	7	8	9
III	a) Clay (loam) in plastic condition b) Sand and clay with the depth of underground water of less than 4 meters c) Gravel and debris with the depth of underground water of less than 3 meters	(+1) 8	(+1) 9	(+1) 10

9. Database for Objects

It was recorded and photographed a total of 980 buildings on the field, of which 976 objects were recorded by geodetic surveying the field, while four (4) "new" facilities were spotted during the site visit and in the geodetic survey they were marked with a circle and the last ordinal numbers. A number of facilities surveyed and recorded in the database, were not processed or photographed, because the owners did not allow the access to or did not want to give details, because in those objects are embassies and consulates. A total of 980 facilities were geodetically recorded and photographed. For these facilities, geodetically recorded, a database was created.

10.Conclusion

The area encompassing regulatory plan "Soukbunar" and beyond belongs to the so-called Dinaric neotectonical area or, neotectonic zone with Middle-Bosnian valleys and is located in the epicentral area of Treskavica-Sarajevo. The observed terrain is made of layers of Lower Triassic (T_1), Middle Triassic limestones (T_2^1), Neogene sediments of Upper Miocene ($^1M_3$) and modern Quaternary sediments (Q) in form of a surface covering.

On the subject area according to engineering-geological composition and properties of soil and rocks, separated are two basic areas: Quaternary cover and geological substrate. Beneath the surface covering, which occupies the largest area of the terrain, there are geological substrate decomposition crust of Upper Miocene sediments and Verfene decomposition crusts. Geological substrate contains sediments of Upper Miocene, Middle Triassic limestones and Verfeneclastic sediments. Parts of the terrain, made of substrate rock masses, can be in terms of geological structure considered optimal favorable for construction and in the coverings materials and decomposition crusts cheap and conditionally favorable terrains or areas with smaller and larger restrictions, which can be solved technically.

In hydrogeological terms, poor and medium-permeable layers of blankets inter-grained porosity are spread on surface, as well as medium and good permeable Anisian limestones, withfracture-karst porosity in function of the aquifer (collector). Beneath them, as floor barrier, Verfene sediments lie and through them in form of overlying barrier, that is hydrogeological insulator lie impermeable rocks of the Upper Miocene.The basic level of seismicity of the Sarajevo city and the observed terrain is 7° MCS.

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