Assessment of the geotechnical conditions of unstable terrain for urban planning of the Umka settlement, Yugoslavia

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Abstract: Belgrade's rolling area and its surroundings are known for the occurrences of instability. Until recently only a 1000 landslides have been recorded, mainly in low boundary terrains oriented towards the rivers Sava and Danube. Their slopes are prevailingly made of Miocene-Pleistocene complexes of soft rocks: clays, marls and sands.

The cause for these numerous landslides is due to the complex geological and morphological evolution of the terrain. However, often the result of human building and economic activity is the cause. As a consequence numerous new landslides have taken place with the reactivation of the old ones.

The Umka settlement is located near the Sava River in a suburb of Belgrade. In the course of four decades there has been extensive urbanization that has also extended itself onto the unstable parts of the terrains. The extension of the settlements was not followed-up in synchrony with the construction of communal infrastructure, thus causing the reactivation of old landslides that spread over 500 apartment houses and cottages. In addition to pronounced erosion of Sava River, large-scale landslide processes became intense particularly after the development of a water-supply network that was not accompanied by sewerage works. Within several decades the problems were ensuing and have the features of natural disasters.

In order to prepare the urban plan of Umka settlement (700 hectares in size) our establishment prepared the geotechnical documentation that have helped to determine the land use for the terrains. The geotechnical documentation has been made in accordance with the detailed engineering geological investigations of terrain and by relying on the results of geotechnical monitoring of the Belgrade-South Adriatic motorway on the banks of the Sava River.

Five large unstable slopes have been recorded in the area under study, with very spacious and mainly deep landslides of different levels of activity. Overall the area that contains landslides amounts to 310 hectares, or 44% of area under study, with 170 hectares of active landslides and 140 hectares of mitigated landslides. Total volume of landslides is approximately 20 000 000 cubic meters.

Résumé: La région de colline de Belgrade et son large environnement sont connus par des manifestations d`instabilité, surtout exprimées dans les parties plus inférieures et en bordure des terrains, qui sont orientées vers les rivières Sava et Danube. Leurs pentes forment en majorité des ensembles du miopliocen de roches tendres : argiles, marnes et sables.

Les causes essentielles de nombreuses apparences de vastes glissement de terrain, sont attribuées à la complexité de l`évolution géologique et morphologique du terrain. Pourtant, la cause directe, aujourd`hui, le plus souvent est le résultat de la construction et de l`activité économique humaine. Ce qui produit de nombreux nouveaux ou réactive de vieux glissements de terrain.

La commune Umka se trouve au bord de la rivière Save dans le quartier de Belgrade. Les quatre dernières décennies ont apporté un urbanisme intensifie qui s`est élargi dans les parties instables du terrain. L`élargissement de la commune n`avait pas suivi l`exécution de l`infrastructure municipale et des mesures d`amélioration du terrain, ce qui a réanimé les vieux glissements de terrains qui ont saisi plus de 500 bâtiments de logement et de résidences secondaires. L` intensification des processus de glissements de terrain de grandes proportions a été produit l`érosion intensive de la rivière Sava, surtout après l`installation des réseaux d`eau qui n`a pas suivi la construction de la canalisation. De cette façon sont engendrés des problèmes qui après quelques décennies prennent un caractère de catastrophe naturelle.

Pour le besoin de l`exécution du plan urbanistique de la commune Umka, qui est répartie sur 700 hectares, l`Institut pour les routes a.d. de Belgrade a préparé une documentation géotechnique, dans laquelle ont été défini les conditions d`urbanisme.

Sur l`espace examiné est enregistré cinq grandes surfaces instables, avec des vastes et profondes surfaces de glissement, avec différent degrés d`activité. La surface totale saisie par les surfaces de glissement est de 310 hectares, ce qui est environ 44% de l`espace concerne, avec 170 hectares de glissements de terrain actifs et 140 hectares de glissements de terrain modérés. Le volume total des glissements de terrain est d`environ 20 000 000 m^3.

Keywords: Landslides, terrain analysis

INTRODUCTION

Belgrade rolling area and its surroundings are known for the occurrences of instability, and this is particularly stressed in the valley banks of rivers Sava and Danube and their major tributaries (Fig. 1). Genesis of numerous and very often large - scale landslides is awarded to complex geologic and morphologic evolution of terrain. However, direct motive, in our time is more often as the result of human building and economic activity.

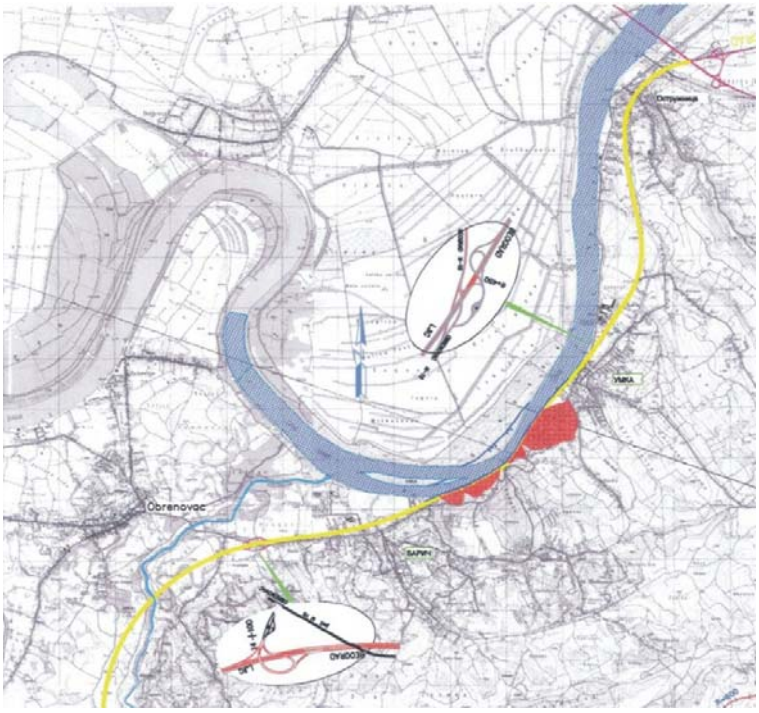

Figure 1. Geographical location

Spacious and deep old landslides, on the stretch from Umka to Baric, formed, along the right bank of the Sava river's great meander, by the beginning of the previous century during the construction of the Belgrade - Uzice, railroad line has been avoided thanks to the geologist Prof.M.T.Lukovic. However, it was left to urban planners and road engineers to tackle these complex and active landslides.

Detailed geologic - geotechnical investigations of these landslides started in 1979, after the decision had been made regarding the route and design of the Belgrade – Umka – Obrenovac motorway which continued onwards to the South Adriatic. Additional investigations and monitoring of the landslides have been resumed in 1990-93 and by the beginning of 2005. The preparation of the Preliminary design of the transport facility thereof is underway. Several possibilities of setting the motorway within the zone of landslides have been taken into consideration. Two variants have been shortlisted: 1st - along the slide foot (i.e. by lowering the road base levels into the river) and 2nd - by its stretching outside the landslides (by the middle of present Sava river channel). The first variant is more cost - effective, interventions in the river channel are lesser, and the main cause of sliding is removed, and thus wider uphill area is being stabilized. The second variant has been abandoned since it requires radical relocation of the river flow, from rolling right bank to the flat left bank, by filling the existing river channel and excavating the new one, by dapping the river terrace, which is in fact the protected water - supply source for Belgrade.

In the pervious period, urban planners have tried on several occasions to form a plan of Umka settlement development and subdue the abusive construction of facilities on the landslides. Only by the year 2001 upon the initiative of Belgrade city authorities, Urban bureau and The Highway Institute have been involved to finalize this complex issue. Extensive study area, which is taking up the settlement and its surroundings, is located on two leveled hills and slopes of the right bank of Sava river, and in the valley of Umka stream. Very spacious and mainly deep landslides have been recorded on all slopes, of various levels of activity, which are endangering and damaging the housing facilities, infrastructure and farming land.

The purpose of preparing geotechnical documentation is reflected in encompassing all previous investigations and engineering-geologic zoning, and thus define the requirements for terrain utilization meant for planned facilities and obtainment of entry data for conceptual solutions of amelioration-repair measures for parts of terrains intercepted by mitigated and active landslides.

The entire area is grouped into six urban zones:

- Zone I: Landslide "Umka" and main road M-19 Belgrade - Obrenovac in the area of active landslides (by addressing the issues of whether the repairs to this area are viable and how to provide for the traffic on the road);
- Zones II, III, IV: Take up the terrains of existing and new housing zones (on mitigated and active landslides);
- Zone V: Newly planned accommodation in the Rucka settlement;
- Zone VI: Definition of engineering requirements for the soft alluvium from the Sava River.

THE RESULTS OF GEOTECHNICAL INVESTIGATIONS

The results of extensive field and laboratory investigations have broadened our knowledge on this type of very spread out landslides appearing in Tertiary terrains. The contribution must be awarded to investigation wells/shafts,

piezometers and inclinometers set in the area of landslides. They have allowed us to observe directly the structure of the landslide body, to follow-up the changes of porosity, humidity, permeability, recording and monitoring of discontinuities of potential and active landslide surfaces. Through perennial monitoring one was in a position to establish the mechanism, depth, relative speed, dynamics and direction of sliding, and also the regime of surface and ground waters.

There has been an extensive abusive urbanization in Umka that has been particularly pronounced in the course of past four decades. The sliding process became even more intense after the setting of water - supply system that was not accompanied by sewerage works, in concurrence with terrain requirements.

The area under study of 700 hectares, unevenly inhabited, takes up the plateaus of Sava river (spot levels 73 - 76) and Umka stream (spot levels 80 -100), and rim valley sides of gradients 5 to 15 degrees and crests (spot levels 185 - 199). Umka has the continental climate with average annual precipitation of approximately 700 mm.

The terrain is made of marine - lacustrine sediments of Miocene (marly clays and marls) and heterogeneous Quaternary sediments (colluvial, proluvial - alluvial and diluvial).

Sava river channel shape configuration is complex due to the pronounced meandering, variability of width and profile grade of riverbed. River width within the landslide zone "Umka" is 180 m (with river channel depth 15 - 17 m), whereas upstream and downstream 400 - 650 m (with river channel depth approximately 9 m). Flow regime of Sava river and discharge depend on the condition at the confluence, i.e. from Danube river discharge and operation of hydro - power plant Djerdap. Ruling levels of Sava river are as follows: high 77.00; medium 73.50 and low 70.10 (Figure 2).

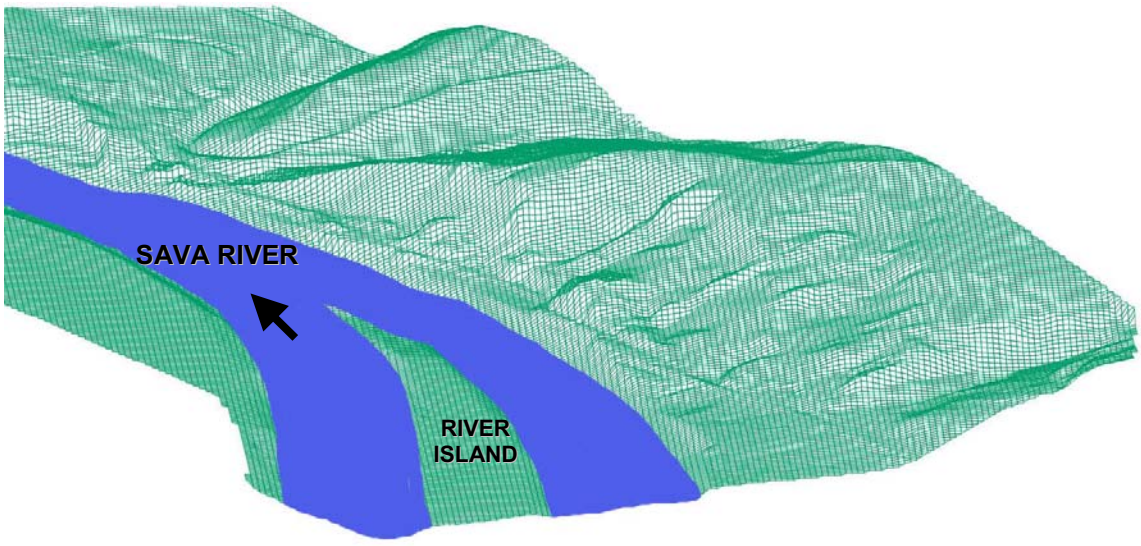

Figure 2. 3D Terrain model

Quaternary deposits and weathering zone of Miocene sediments, due to their respective fabrics, porosity and position within the terrain, from geotechnical point of view they represent "*hydrogeological collecting main*", with prevailingly unfavorable physical-mechanical features. Plastic, degraded clay mass is sliding over the compact, hard and impervious underlying stratum, made of massive and fresh Pannonian marls (M_3^2L). This is one of the main causes for instability occurrence in the region thereof. Basic feature of ground waters is that they are created by the precipitation infiltration and from water - supply system, septic tanks and channels, with the exception of riparian belt of Sava river and Umka stream, where the ground waters regime depends from the water level change.

In the area under study five large unstable slopes have been recorded, and located on the right valley bank of Sava river and in the valleys of streams Umka and Duboko. Entire area intercepted by landslides is 310 hectares, which amounts to 44% of study area, out of which active landslides take up 170 hectares, while mitigated ones take up 140 hectares. Assuming that average depth of landslide amounts to 6.5 m, overall volume of landslides amounts to approximately 20 000 000 cubic meters. Sliding process, in the area thereof, is very old and mainly slow, renewed through the centuries, while the landslides have been also exposed to widening and deepening processes. This is the feature of all similar Tertiary terrains that under the same climate conditions in the littoral parts of big rivers are exposed to intense scouring, erosion and removal of materials set in motion. Landslide depth is predetermined by the weathering zone thickness and by the depth of river and stream channels. Landslides that appeared along the coasts of former lakes, and then rivers, "climbed" progressively up the slopes and moving away from the river mainstream towards some new position or due to the flow regime alteration ensuing from climate changes.

In existing historical - geologic and climate conditions, the terrain is constantly exposed to erosion caused by surface flows - particularly of Sava river and impact of atmospheric precipitation, due to which the occurrences of instability are turned out and still last till nowadays by "transferring" from certain narrow location to another, depending on some new external factor. In our days anthropogenic factors have great impact: entering of large quantities of foul waters, change of flow or regime of water in Sava river and seasonal sudden changes of hydraulic gradient.

Landslide "Umka" is inhabited and is crossed by the road transport facility Belgrade - Obrenovac. In the last forty years extensive population settled the area. Some 500 facilities have been recorded on the landslide itself. In the

period 1960-91 the water - supply system was installed (mainly "abusive network"), whereas 160 dug-out wells turned out into septic tanks (Fig. 3).

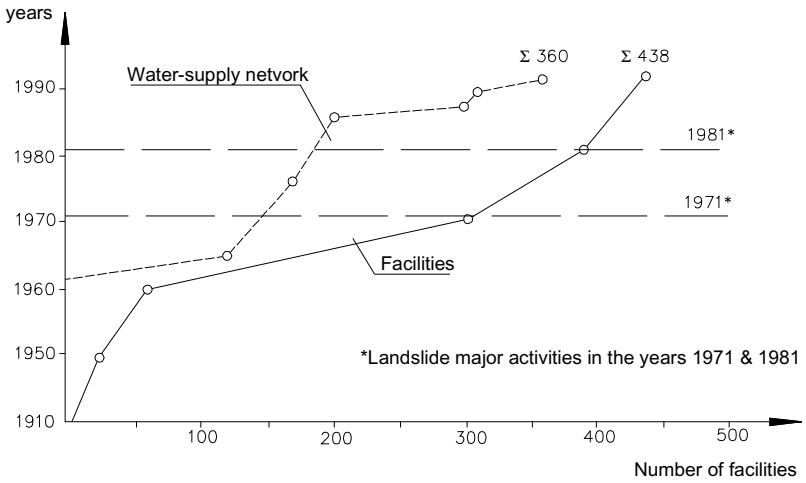

Figure 3. Construction schedule chart

Some 80 % of structures have considerable damages due to terrain sliding. The conditions of structures/buildings as of the beginning of 2005 are as follows: 35 buildings pulled down, 90 buildings prone to tearing down, 260 medium damaged facilities, minor damages on 85 buildings. On approximately 30 units prevailingly built in recent times, no deformations have been recorded (Fig 4. & 5). The scale of damages on buildings thereof is understandable due to great quantities of foul waters entering into the terrain ("underground rivers" with annual discharge of 45 000 000 of cubic meters of water). These "rivers" waterlog and destroy the terrain, by changing its fabric, physical - chemical and mechanical properties.

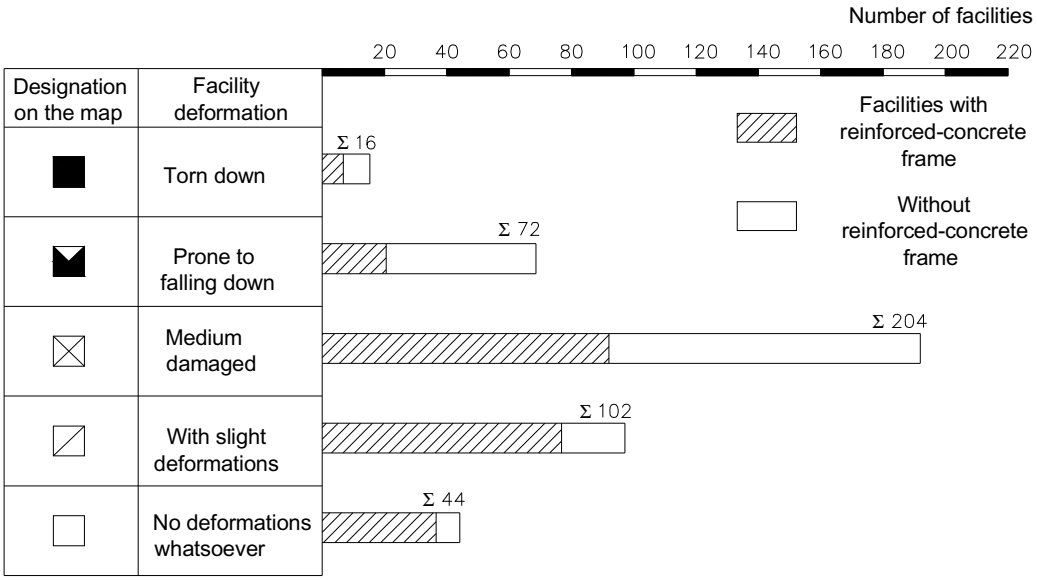

Figure 4. Categorization of facilities as per damage level

Based on essential engineering - geologic features of terrain (geologic fabric, morphology, natural stability, physical - mechanical features of singled-out environments, ground water conditions, etc.) four engineering - geologic districts have been singled-out, being set aside by specific features into six microdistricts. Requirements and recommendations for repair, amelioration and operation have been given for each district as follows:

- District I - river and stream plateaus, with microdistricts Ia (Sava river deposit) and Ib (Umka stream deposit),
- District II - stable crest and slopes, with microdistricts IIa and IIb,
- District III- terrains intercepted by mitigated and active landslides, with microdistricts IIIa and IIIb,
- District IV- area of the right valley bank of Duboko stream, intersected by ravines.

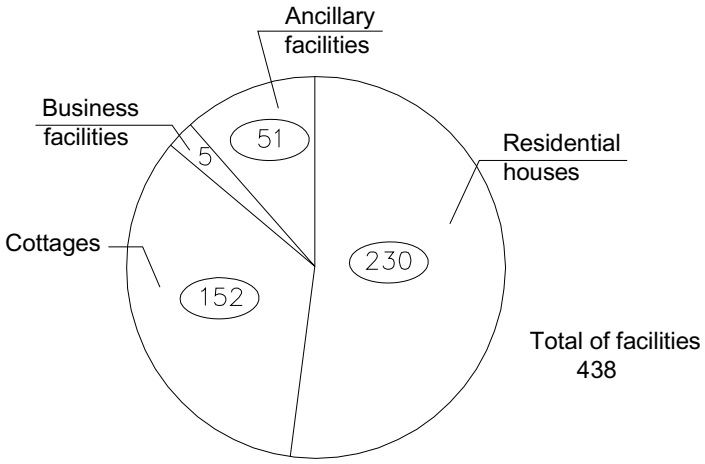

Figure 5. Classification of facilities according to type and purpose

AMELIORATION AND REPAIR MEASURES

Generally speaking, within the framework of amelioration - repair measures, required for the stability of terrain, at the level of Umka urban plan, the following has been proposed (Fig. 6):

- Construction protective - retaining embankment on the right bank of Sava river (Zone I - landslide "Umka"),
- Construction of revetment structures,
- Construction of drainage systems,
- Construction of open channels network for intake and take off of surface waters,
- Grading and skimming of deformed terrain surfaces,
- Afforestation,
- Amelioration of Zone IV terrains exposed to seasonal flooding by building wide embankment.

Natural stability under ultimate limit state of balance has been checked-up by numerous geostatic analyses and the effects of proposed measures of amelioration and repairs have been checked - up as well.

- **Zone I - landslide "Umka"**: Entire zone is located on active landslide on the area of 60 hectares and with depth of 10-25 m (microdistrict IIIb). Very high level of ground water has been recorded. Sliding process appearance an development is predetermined by geologic fabric and hydro-geologic features of this terrain, i.e. by the presence of degraded clayey materials, which under water saturation have properties of reduced resistance. Terrain with gradient 8 - 15 degrees is exposed to the erosion from the right bank of Sava river, then to the impact of surface and underground waters (natural and anthropogenetic origin), thus having deep and active landslide as a consequence. The proposal has been made to stop further construction on the landslide and to contemplate the idea of partial or complete relocation of population. Based upon geotechnical analyses, at the level conceptual solutions, we came up with two variants for repairs:
  - The first variant provides for the stability of "Umka" landslide, i.e. entire urban Zone I. It encompasses the construction of protective - retaining embankment as regulation structure, along the right bank of Sava river, which could have a road bed role for future motorway Belgrade - South Adriatic, section Umka - Obrenovac. By setting the embankment along the right bank demands for the widening of the river channel of the left bank of Sava river channel on the stretch of approximately 2 km. In addition, on the landslide uphill side it is necessary to build drainage systems and retaining structures made of self - supporting AB piles, network of channels for intake of surface and sewerage waters, local skimming and afforestation (Fig. 6).
  - The second variant stabilizes the landslide on narrow belt and guarantees safer traffic operation on the road Belgrade - Obrenovac. Repair measures involve the construction of retaining structures made of self - supporting AB piles, drainage system, channel for intake of surface waters with culverts, local skimming and afforestation of terrain.
- **Zones II & III - existing and planned residence:** These are located on old mitigated landslides of Sava river amphitheater, Umka stream valley and road for Rucka (microdistrict III). Border areas are in danger from active landslides 5-10 m deep. Inhabited zones have water-supply system, yet they do not have rainwater services and sewerage network. Foul waters are entering into the septic tanks. Local channels are damaged and out of function. Umka stream is partly regulated and neglected. Entire area requires the construction of opened and closed channels in order to take off surface and foul waters. The construction drainage and

retaining structures is anticipated as a preventive measure aimed at averting the extension of active and reactivation of mitigated landslides. Umka stream should be cleaned-up and regulated, while the afforestation should be carried out on active landslides and prevent any further construction of facilities.

- **Zone IV** is located in Sava river amphitheater, along the foot of a mitigated landslide, with depth to 5 m, whereon the construction of a new street with dwelling belt (50 m wide) is planned to be built. Gradient is approximately 5°. Ground water level is high, whereas the surface waters, originating from a wide hinterland, gravitate without control towards the alluvial plateau of Sava river. It is anticipated to construct opened channels and drainage system. In the area's backing there is an active landslide anticipated for skimming and afforestation. The facilities can be built only after the implementation of repair measures and construction of sewerage system.

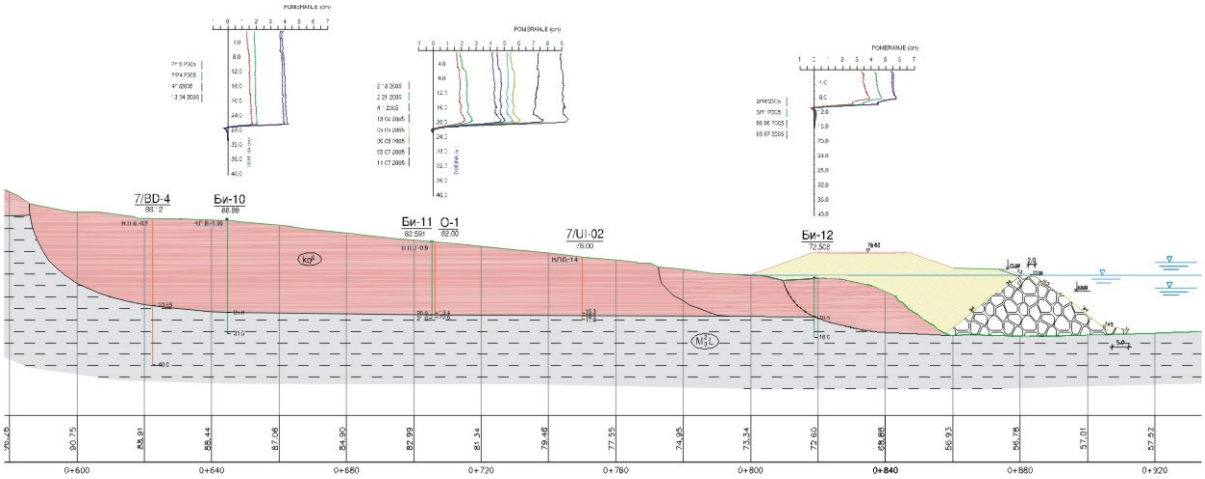

Figure 6. Engineering geological cross section - with repair measure and terrain reclamation

- **Zone V - newly planned dwelling in Rucka settlement** takes up stable terrain, high hilly plateau suitable for urbanization.
- **Zone VI -** takes up wide alluvial plateau of Sava river, spot - levels 72-73. River deposit, 10-13 m thick. Made of variably bearing silty - sandy, locally muddy clays and sands. Ground water is seasonal on terrain surface. Land reclamation is anticipated by the construction of wide embankment made of dredging sand. Spot - level of filling is two meters above the medium water level of Sava River. Terrain consolidation and improvement of soil's resistance properties vs deformations will be caused by embankment's subsidence (10 - 15 cm) to be carried out within a year. Drainage of soil will be improved by building the channel towards Sava River. Repaired area could be utilized for the parks, sporting facilities and construction of minor structures.

CONCLUSION

Old landslides formed in the valleys of river Sava and Umka stream, were created in Miocene complex of clays and marls, and thus resulted from complex geologic and morphologic evolution of terrain. Clayey colluvium thickness is variable, in hypsometrically higher parts of terrains it amounts most frequently to 5 - 10 m, whereas in the littoral part of Sava River it amounts to 20 - 25 m.

Sliding process is the consequence, from physical - mechanical properties of highly plastic clay which in dampen state turns out the features of low resistance (φ = 7 - 13°, c_r = 0 kPa) on one side, and from permanent hydraulic link of ground and river water, as well as by the exposure of landslide foot to scouring and erosion of directed mainstream of Sava river on the other side. Very active sliding process in inhabited slope parts of Umka is the consequence of uncontrolled construction and perennial entering of great quantities of foul waters into the terrain.

Further urbanization of Umka must be constrained on stable terrains with compulsory construction of canal and sewerage network in order to take off surface and foul waters. Parts of old landslides, encompassed by urbanization, should be repaired and hydrotechnically arranged, through the construction of drainage and retaining structures.

The most vulnerable part in the riparian zone of Sava river will be stabilized only after the construction of an embankment that will prevent the undermining of unstable slope.

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