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THE CONTRIBUTION TO THE GROUNDWATER QUANTITIES CALCULATIONS IN CRITICAL SECTIONS OF LANDSLIDES – EXAMPLE LANDSLIDE „MRAKUŠA“ IN SARAJEVO

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SUMMARY

The hydrogeological investigations are inevitable in the whole process in defining of engineer-geological field characteristics and the drafting of landsllides rehabilitation project, but the main goal of these investigations is the groundwater quantities calculations in critical sections of landslides. For gain of exact input parameters for groundwater quantities calculations in critical sections of landslides, it is neccessary to define hydrogeological categories and the function of rock masses, the rock filtration characteristics, hydrodynamic characteristics of groundwater, the level and the angle of groundwater, hydraulic gradient, the directions and filtration speed of groundwater, the conditions of intake recharge and draining of groundwater, hydrogeological and hydrochemical characteristics of groundwater and other factors and elements of groundwater regime. In this paper the example of groundwater quantities calculations in critical sections of landslides is shown, based on the results of hydrogeological investigations and examinations in rehabilitation of landslide “Mrakuša” in Sarajevo.

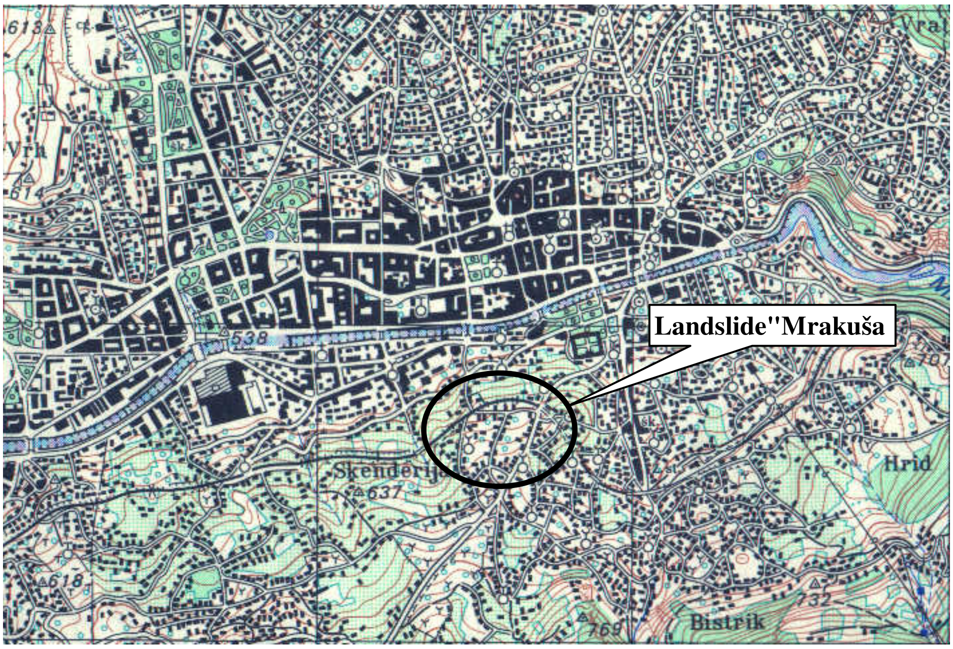
Key words: *landslide, filtration, groundwater level, groundwater regime and quantities of groundwater*

INTRODUCTION

The institute for geology of civil engineering faculty in Sarajevo during 2007. has made a recultivation project of „Mrakuša” landslide in Sarajevo [1]. Drafting the mentioned project a wide hydrogeological investigations and examinations, for groundwater quantities calculations in critical sections of landslides were done, and all that for purposes of defining the hydrogeological function and categories of rocks, the filtration conditions, the hydrodynamical characteristics of groundwater, the level and the angle of groundwater, hydraulic gradient, the directions and filtration speed of groundwater, the conditions of intake recharge and draining of groundwater, hydrogeological and hydrochemical characteristics of groundwater and other factors and elements of groundwater regime.

LANDSLIDE LOCATION

The "Mrakuša" landslide is located in the urban part of Sarajevo, on the northwestern hillside of Trebević mauntain, picture 1. The area of the landslide is 15,5 ha.



Picture 1 The location of "Mrakuša" landslide, scale 1: 25.000

GEOLOGICAL FIELD CHARACTERISTISC

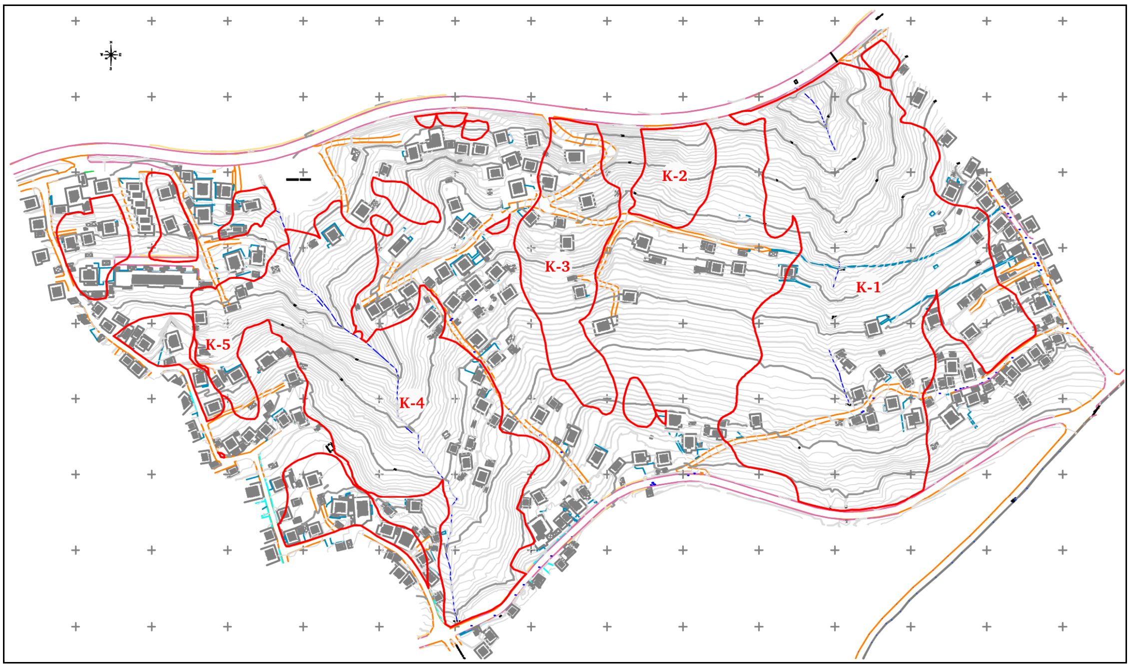
The geological basis (supstrate) of the field is made of lower triassic (T_1) sandstones and claystones, middle triassic (T_2^1) limestones and upper miocene ($^1M_3$) clays and marls [2]. The rock complex of the geological basis is covered by quarternary eluvial-deluvial (el-de) and coluvial (kl) deposits, which are mainly sand-clayey composition in 2-10 m thickness.

ENGINEER-GEOLOGICAL FIELD CHARACTERISTICS

Regarding the engineer-geological field characteristics, the terain is made of quarternary covering and geological supstrate [3]. The quarternary covering is represented by anthropogenic embankment materials, eluvial-deluvial deposits and coluvial materials. The 1,5m embankment is made of sand, limestone fragments, debris and setts. The 4,0m eluvial-deluvial covering is made of humus, sandy clays, finegrained debris and sporadic setts. These deposits have in a dry condition good abilities, but when saturated with water, they turn into easy movable mud-slurry like mass. These deposits are, when natural humid, pervious to swelling and increased subsidence. The eluvial-deluvial covering, seen as a whole, is representing a benign area for landslides, and the contact to the geological supstrate represents the critical discontinuity for landslide genesis.

The coluvial materials are made of cohesive and cohesionless materials, mainly clay, clayey debris, sand, gravel and setts, which are in composition similar to the eluvial-deluvial rocks. The thickness of coluvial materials is from 1,7m – 7,7m. The physical-mechanical conditions of this horizon is very variable, with low values, which indicates on its deformability and instability. The geological supstrate is made of heterogenic complex of sand-marl-clayey deposits of upper miocene ($^1M_3$), megasetts of limestones of middle triassic (T_2^1) and in the Trebević sole by lower triassic (T_1) claystones.

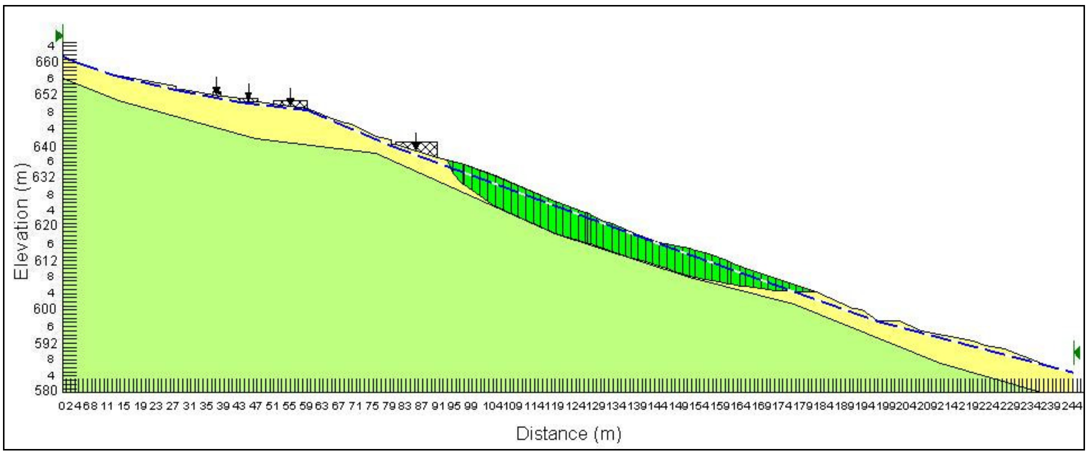
In the landslide „Mrakuša“ zone (picture 2) five separate landslides were isolated. (landslides K-1 to K-5). The isolated appearances represent pseudo calm landslides, where only a few recent, active (fast) processes have taking place and a few sporadic and abrupt ones. Generally, on the hillside are very slow gravitational moves of the rock and soil masses towards the road in the hillside sole.



Picture 2 The location of landslide K1 – K5 "Mrakuša" (M.Bašagić et.al 2007.)

THE CAUSE OF LANDSLIDE GENESIS

The cause of landslide "Mrakuša" genesis can be reduced on the following: 1) the predisposition of the geological conditions, which the hillside slope is made of. In fact, these are rocks on clay basis, which are submissive to weathering and forming of clay-sandy coverings; 2) the uncontrolled intake, flow and infiltration of surface water on the hillside (landslide areas); [4]; 3) uneven intake and flow of groundwater within the surface coverings and above the unpermeable unit, what reduces the stability in the whole hillside; 4) relatively deep covering of poor geotechnical characteristics; 5) uneven inclinations of the hillside and slide units; 6) uncontrolled and unadequate construction of objects and roads, and of course the diffusion of waste water along the hillside and through the landslide body.



Picture 3 The characteristic landslide "Mrakuša" cross section (M.Bašagić et.al 2007.)

THE INVESTIGATION AND EXAMINATION METHODOLOGY

The investigation works and examinations involved: 1) geodesic works; 2) engineer-geological and hydrogeological mapping (16 ha); 3) explorational drilling (39 boreholes) with associated shallow trials; 4) geological borehole core mapping and sampling for geomechanical examinations; 5) drafting of inclinometric boreholes (2 pcs); 6) geomechanical examinations on disturbed and undisturbed samples (116 samples); 7) groundwater measuring and registration; 8) groundwater regime study; 9) groundwater borehole pumping trials.

HYDROGEOLOGICAL INVESTIGATION RESULTS

Hydrogeological categorisation, areals and function of rocks

The landslide "Mrakuša" terain is made of: permeable intergranular rocks, permeable karst-fissure rocks and unpermeable rocks [5]. Permeable intergranular rocks are cohesionless or with a low cohesion eluvial-deluvial (el-de), coluvial (kl) and embankment (n) deposits. They are built of sandy clays, clayey debris, sand, gravel and setts. The thickness of these deposits varies from 1,3-10,5m. These deposits are classified as lowpermeable, with hydraulic conductivity coefficient K=2,0 x 10^{-6}-9,0 x 10^{-7} m/s and transmissivity coefficient T=1,0-8,0 x 10^{-6} m^2/s. The permeable intergranular sediments are in function of subsurface aquifer with low or less continous spreading, but with a low thickness and capacity and with periodically fast and abrupt water exchange. The permeable karst fissure rocks are represented as middle triassic (T_2^1) limestones. Its thickness were not estimated in the zone of landslide, while in the area of Trebević the thickness is about 300m. According the carstification degree, these limestones are classified as rocks with a transmissivity coefficient T=10^{-4}-10^{-5} m^2/s [6]. In the unpermeable category are low or well petrified clastic deposits of upper miocene ($^1M_3$). These deposits are marly clays, layered marls, thinlayered alevrolits and layers of weathered sandstones. Its thickness is 100-150m, and they have a function as lateral hydrogeologic barrier.

Hydrogeological aquifer characteristics

In the "Mrakuša" landslide zone some subsurface aquifers were formed, which are represented by eluvial-deluvial and coluvial deposits. The named deposits are as a hydrogeologic complex where the lithologic units are alterated lateral and vertical. The thickness of these deposits is relatively small and amounts 1,3-10,5m.

The filtration characteristics of the aquifer are weak with low values of hydrogeologic parameters, which are calculated based on the J a c o b nonstationary flow conditions pumping tests results and based on the granulometric sample analyse from the boreholes, according to U S B R.

Table 1 Average values of hydrogeologic parameters in the zone of isolated landslides

Landslide	K (m/s)	T (m^2/s)
K1	9,8 x 10^{-7}	2,9 x 10^{-6}
K2	2,5 x 10^{-6}	7,5 x 10^{-6}
K3	3,5 x 10^{-7}	1,3 x 10^{-6}
K4	3,5 x 10^{-7}	1,1 x 10^{-6}
K5	7,3 x 10^{-6}	2,2 x 10^{-6}
Average values:	2,3x10^{-6}	3,0 x 10^{-6}

The groundwater level in the unconfined aquifer is according the terain and relatively near the surface. The hydrodynamical characteristics of the groundwater indicates on sporadic variation of lateral and vertical changes of filtration characteristics. When considering that the waterbearing deposits are sporadicly eroded in the river valley, we can say that the aquifer in the area of „Mrakuša" landslide has no continous spreading. It is important to say that the sporadic wastewater disposal and the occasionally damage of water-supply pipes can affect on the local change of hydrogeologic relations. As a result, we have a disturbance and sporadic various intake recharge process, flow direction and groundwater drainage, what results in lower or higher waterholding abilities of the terain. The hydroisohypses are following the terain morphology with a main direction east-west. The inclination of the groundwater level is in southern direction.

Sporadicly there are some smaller deviations from the named directions in the Gaj and Žagarići streams, as a result of stream incise. The hydraulic gradient is from I = 0,2 – 0,5, which is relatively high in some parts of the terain.

Table 2: Appearance of water in explorational boreholes

Landslide	First appearance on depth (m)	24 hours after drilling (m)
K1	2,20 - 10,50	0,30 - 9,60
K2	2,00 - 6,00	3,55 - 7,62
K3	2,70 - 8,40	4,99 - 7,95
K4	3,00 - 9,20	2,00 - 9,20
K5	2,30 - 9,50	2,00 - 6,90
Average:	2,44 - 8,72	2,56 - 8,28

The groundwater flow direction in the area of „Mrakuša" is has a south-north bearing. Midst the regime disturbance the flow direction deviates from the main bearing and folows the direction of some local landslides. *The groundwater filtration velocity* has been determinated based on the hydraulic conductivity (K), hydraulic gradien (I) and aquifer porosity (n).

Table 3 Groundwater hydraulic conductivity in sonme landslides

Landslide	Hydraulic conductivity (cm/dan)
K1	4,15
K2	12,9
K3	2,60
K4	1,30
K5	4,61
Average value:	5,11

Based on the given values, low hydraulic conductivity values could be seen. Some higher values are in the zone of K2 landslide, most probably because of former built in drainages in this part of terain.

Intake recharge of the aquifer is based on precipitation and the streams Gaj and Žagarići. An exclusion of wastewater intake recharge could not be done, what can be confirmed by high electro conductivity in some springs (spring in the K5 landslide - Ep=782 μS/cm). It must be said that wastewater from a greater number of individual houses is disposed on the hillside or in some unscheduled sewers.

Aquifer draining is manifestated by a higher number of occasionall springs, diffuse flows and higher humidity in some terain parts. The main characteristics of water phenomena in the „Mrakuša" area is a low capacity, unsteady appearance and high hypsometric differencies in a disposition. The low capacity is a result of low filtration characteristics, its proportion, groundwater regime and recharge conditions. The unsteady appearance is a result of terain morphology, landslide processes and antropogenic conditions.

The biggest presence of water appearance is in the K1, K4 and K5 landslide zones, while looking from the aspects of hypsometry, ffrom 590-670m. In the K1 landslide zone a diffuse flow is the dominant one with a capacity Q = 0,05-0,1 l/s. The biggest appearance of difuse flow is under the Cicin Han street – the Hambina carina cemetary. In the K2 and K3 landslide zones, except the small number of wet terain appearances, other water appearances were not registered. The reason of that are the old and individual drainage objects, made in the first zone of the terain, which caught a part of groundwater, which were before that on the surface. In the K4 landslide zone a dominant appearance of constant diffuse flow is present. These flows are especially present in the secondary landslide zones, house basements, etc. In the K5 landslide zone different water appearances are present, constant diffuse flow, permanent and periodic springs with Q = 0,05-0,1 l/s, and water catchments Q = 0,1 l/s. The flows are abducted into the sewage, and some are used as public fountains, but the other part of these water appearances are, after infiltrating into the basements, abducted on the terain, which are infiltrating into the underground.

Režim podzemnih voda rejonu klizišta „Mrakuša" je složen, promjenjiv i mjestimično narušen. Odražava kvantitativno i kvalitativno stanje podzemnih voda u toku vremena, kao rezultantu uzajamnog djelovanja niza prirodnih i vještačkih faktora. Među prirodnim, za analizu režima od veće važnosti su geološki, klimatski, hidrološki i biološki faktori, a od vještačkih, drenaže, kanalizaciona i vodovodna infrastruktura.

The groundwater regime has been monitored in the boreholes. The monitorings were started in the hydrological minimum from 15.08. – 08.10.2007. The groundwater level indicates some oscilations, what depends from the hydrological terms, precipitation and stream flow. The K1 landslide shows that the groundwater level in the B-2 and B-12 boreholes has no oscilations during dry periods (from 15.08.-22.08.) and right after a rainfall (15.09. and 08.10.). The groundwater level in the B-1, B-4, B-11 and B-13 boreholes indicates on oscilations with level fluctuations ΔH = 0,20 - 1,4 m.

The afterwards rising of the groundwater level in boreholes B-3 and B-9 is caused probably by infiltrating of surface water into the underground. The K2 landslide shows that the groundwater level in B-15 and B-16 boreholes is stable in dry period and after a rainfall the GWL is on the depth of 6,0m, what is close to the first water appearance i the B-17 borehole.

The GWL in the K3 landslide is monitored only from the B-22 borehole and the level shows fluctuations about ΔH = 0,33 m. The GWL in the K4 landslide is monitored through the B-25, B-26 and B-31 boreholes and shows no significant oscilations in dry periods and right after a rainfall. The fluctuation amplitide is from ΔH=0,16-0,42 m. In the B-23 borehole the GWL oscilation is most present, with a fluctuation amplitude of ΔH=1,12 m. The B-24 borehole was after its completition dry, but it shows afterwards a big increase of GWL, probably by surface water infiltration.

On the K5 landslide the GWL in boreholes B-33 and B-34 shows no oscilations in dry periods and periods after a rainfall. The presence of water in a dry B-32 borehole is probably caused by infiltration from the nearby public fountain.

Examining the grounwater levels in all 5 (five) landslide bodies, it can be said that a higher amount of water infiltration can be expected, with a higher amplitudes and fluctuations. The monitorings should be continued, at least until october or november.

Groundwater quantities in critical sections

The groundwater quantities in critical sections of some landslides are estimated as empirical, based on hydraulic conductivity values (K), hydraulic gradient (I), average aquifer thickness (h_{sr}) and the width of the aquifer (B). As mentioned, the hydraulic conductivity values are estimated based on the pumping tests and granulometric analyses, while the values for hydraulic gradient were estimated based on the GWL position in the boreholes.

Table 4: *Groundwater quantities in critical sections of isolated landslides*

Landslide	Quantities of water	
	(l/sec)	(m^3/s)
K1	0,1	1,05 x 10^{-4}
K2	0,08	8,25 x 10^{-5}
K3	0,015	1,59 x 10^{-5}
K4	0,04	4,09 x 10^{-5}
K5	0,2	2,09 x 10^{-4}
Total:	0,44	4,4 x 10^{-4}

The critical sections in some landslides were located in the zones of increased flowouts. The groundwater quantities are very low in dry periods, but an increace during rainfalls can be expected, so that some tests should be examined during humid periods.

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