UNDERGROUND MINING ENGINEERING 23 (2013) 45-58 UDK 62
FACULTY OF MINING AND GEOLOGY, BELGRADE YU ISSN 03542904

Professional paper

GEOTECHNICAL ZONING OF TUNNEL EXCAVATION SITE OF TUNNEL "VIŠNJICA"

GEOTEHNIČKO ZONIRANJE TUNELSKOG ISKOPA TUNELA "VIŠNJICA"

Majstorović Jelena[1], Vukadinović Isidora[2], Ilić Saša[1]

Received: October 22, 2013 **Accepted:** December 01, 2013

Abstract: Tunnel "Višnjica" is a part of collector "Interceptor Ušće – Veliko Selo" that is going to be the main Belgrade municipal sewerage system. Twenty-one inquiry borings (1,254 m of boring) were performed on tunnel route and representatives for laboratory investigation were separated from them. Laboratory investigation was aimed at getting parameters that would enable distinguishing of geotechnical categories on distinctly heterogenous terrain. In order to define geotechnical conditions for building construction, geotechnical zoning of terrain in the area of excavation site was performed. It was performed according to lithological structure of distinguished lithological complexes, thickness of upper layer, resistant-deformable properties of distinct environments and the possibility of water occurence at excavation site. Based on distinguished geotechnical areas and their characteristics, geotechnical categorisation of excavation site into four categories was done. All categories were appropriate for hydro-shield method application.

Key words: tunnel, collector, resistant-deformable properties, excavation method

Apstrakt: Tunel "Višnjica" je deo kolektora "Interceptor Ušće - Veliko Selo", koji treba da postane centralni kanalizacioni sistem Beograda. Na trasi tunela izvedena je 21 istražna bušotina (1254 m bušenja) iz kojih su izdvojeni reprezenti za laboratorijska ispitivanja. Laboratorijska ispitivanja bila su usmerena na dobijanje parametara koji će omogućiti izdvajanje geotehničkih kategorija u izrazito heterogenom terenu. Za potrebe definisanja geotehničkih uslova izgradnje objekta izvršeno je geotehničko zoniranje terena u zoni tunelskog iskopa. Zoniranje je izvršeno prema litološkom sastavu izdvojenih litoloških kompleksa, debljini nadsloja, otporno-deformabilnim svojstvima izdvojenih sredina i mogućnosti pojave vode u iskopu. Na osnovu izdvojenih geotehničkih zona i njihovih karakteristika urađena je geotehnička kategorizacija iskopa u četiri kategorije. Sve izdvojene kategorije pogodovale su primeni metoda hidroštita.

Ključne reči: tunel, kolektor, otporno-deformabina svojstva, metoda iskopa

[1] University of Belgrade - Faculty of Mining and Geology, Djušina 7, 11000 Belgrade, Serbia, e-mails: jelena.majstorovic@orion.rs; sasa.ilic@rgf.bg.ac.rs
[2] Geological Survey of Serbia, Rovinjska 12, 11000 Belgrade, Serbia.

1. INTRODUCTION

Collector "Interceptor Ušće - Veliko Selo" is going to be the main Belgrade municipal sewerage system. Tunnel "Višnjica" that is located at the line "Višnjica - Veliko Selo" is the part of this collector and come from km 6+800 to km 12+369 stationary chain. The height of upper layer is 6.00 m to 200.00 m. Previous examination of wider surroundings of investigated terrain points to very complex and insufficiently explained geological structure in which the oldest are sediments of lower Miocene ($M_{1,2}$) – sediments of so called "multi-coloured series". Kosovoprojekt did first works in 1978. Further explorations necessary for updating the preliminary project, and later also the main project were done in the period of 2004 - 2005, when in all 21 exploration drillholes (1,254 m drilled) were carried out. Following geomechanical investigations were performed on representatives separated from exploration drillholes: identification and classification tests, uniaxial compressive strength tests, direct shear tests, tensile strength tests, swelling tests and tests for determining dynamic properties. During investigation, it was found that it is necessary for some representatives, in addition to uniaxial compressive strength test at initial humidity, to perform test of this parameter after moistening. Tests that were performed on representatives (samples) together with terrain investigation were aimed at selection of the most appropriate method of tunnel excavation. In addition, the knowledge of geomechanical lithological members of "multi-coloured series" was especially increased.

2. GEOLOGICAL STRUCTURE OF INVESTIGATED TERRAIN

In the area of "Belgrade Danube key", the oldest sediments that were registered by investigative works are sediments of lower Miocene ($M_{1,2}$), i.e. sediments of so-called "multi-coloured series". The thickness of this series exceeds 300 m. The series is named according to frequent and alternating change of colour. Within the series, the change of lithological members that compose it is also frequent – marly and tuffaceous clays, marls, gravels, sands, tuff and conglomerates. Transitions between them are often very gradual. The series is, by the conditions of formation that have affected the type and composition, and by that further characteristics of these sediments, divided into 3 formations, from the oldest to the most recent:

- Velikoselska;
- Slanačka, and
- Bučvar.

The following lithogenetic complexes present Velikoselska formation: gravely clays - (SG) in the shelf, clays and sands - (G, P) and marly clays with the tuff and tuffites debris (LG, θ) in the roof. Within these sediments, clays of massive structure dominate and they are divided by cracks with striae of different orientation and slope. Sands, gravels, conglomerates and tuff are in form of lens and inter-layers and their dimensions are in meters. Sediments are diverse in colour, they are yellow, orange, gray, green and red. Sediment thickness of this formation exceeds 100 m.

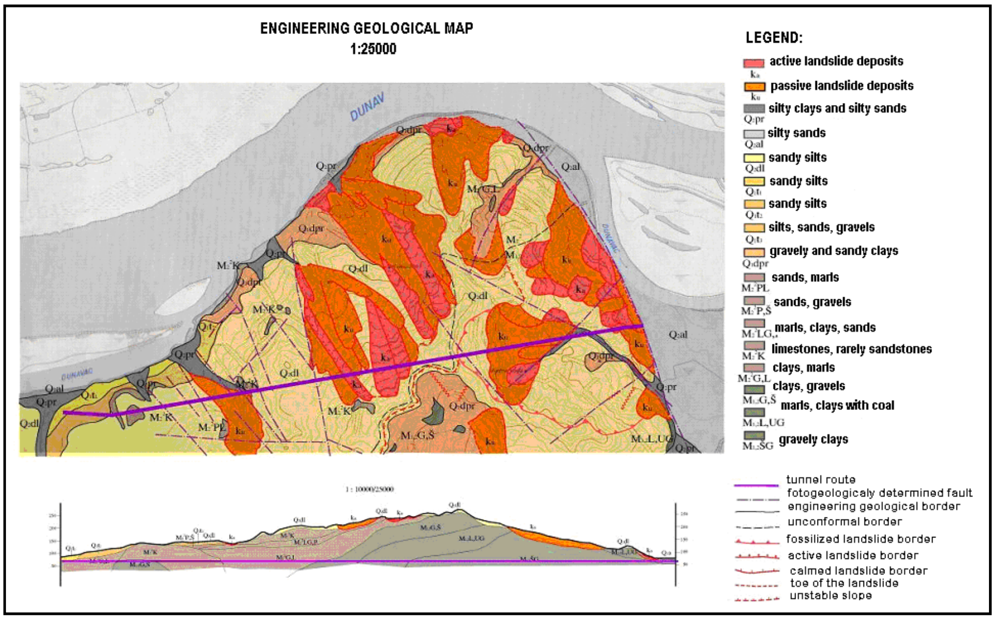

Figure 1 - Engineering geological map of the area of "Belgrade Danube key" with the route of "tunnel Višnjica" (Vukadinović, 2005)

Within the Slanačka formation, there are two lithogenetic facies:

- Lake facies, marl and marly clays (L), which thickness is around 70 m. Marls are from massive to laminar texture, which is easily noticeable and has bright gray-green colour. Laminae slope is 5^o - 7^o. There are frequently layers of bentonite in the mass. Clays are of massive texture and have brown colour.
- Clays, coal clays and coals represent terrestrial facies. During engineering geological mapping of drillholes, cyclic repeating of sediments was noticed and these sediments begin with dusty sands, dusty-sandy clays and are completed with clays. The colour of package is from gray-blue to brown. Total thickness of sediments is around 20 m - 30 m. Layers of coal (peat) appear in two, i.e. three levels, which thickness is 0.5 m - 2.0 m and, according to previous investigators, even to 3.0 m.

Bučvar formation, which is the youngest package of "multicoloured series", is represented by clays, marls, sandy-marly and tuffaceous clays, with inter-layers of gravels, weakly tied sandstones and conglomerates. It consists of 4 lithogenetic complexes: clays and marls (G, L), sandy clays and marls with accumulations of tuffaceous dust (PG, L, θ), marly - sandy clays and marls with gravels (LPG, L, S) and marly - sandy tuffaceous clays and marls (LPG, L, θ). These sediments have distinctly heterogenous composition and frequent lateral replacement and are represented by varieties of blue, gray-green and orange-brown shades. Tuff and tuffites inter-layers appear at several levels which total thickness is 1.0 m - 5.0 m. The thickness of this complex in east part of the explored area is around 85 m while in the area of Višnjica, the thickness of these sediments is much greater, around 150 m.

The Baden sediments (M_2^2) build the western parts of the terrain, mostly the area of Višnjica and Višnjička Banja. Marine sediments of changeable facial development represent them. The thickness of the sediments varies from 10 m to over 150 m and their general slope is toward south-west and north-west.

Within Baden sediments, three sub-floors are separated:

- Lower Baden ($^1M_2^2$) in which complex of basal conglomerates and sandstones (KG, PS) and complex of marly clays and clay-sandy marls (LG, GPL) are distinguished. Total thickness of these sediments does not exceed 30 m. They lean immediately on sediments of Bučvar formation and the slope of series is generally toward north-west and south-west. The complex (KG, PS) is represented by weakly tied sand and sandstones in the roof, weakly clayey gravel, half-tied conglomerates and limestone debris in shelf. Total thickness is 5.0 m - 7.0 m.
- Marly clays and clayey-sandy marls (LG, GPL) of dark green colour appear in roof of basal series. Inter-layers of marlstones of whitish colour, thick to 5 cm, rarely appear in them.
- Transitional facies between lower and middle Baden ($^{1,2}M_2^2$) is represented by organogenetic sediments, which belong to the basis of sandbar, marly-clayey composition (K_{LG}) of grayish colour and sandstone (PS) as transitional layer - the edge of sandbar. Thickness of the basis of sandbar is over 30 m and their shelf is, the most probably, represented by sediments of "multicoloured series".

Deep-water marine sediments of different lithological composition represent middle Baden ($^2M_2^2$). Main complexes within this sub-floor are:

- Clayey marls and marly clays (GL, LG), of dark brown to dark green colour and of massive texture. Lamination rarely appears in them. They are sandy in places.
- Limestones (K_L) - organogenetic, sandbar, marly to sandy, cavernous, of massive texture and yellowish colour. Lens-like inter-layers of marly clays are present in them, as well as caverns filled with dusty material.

Upper Baden ($^3M_2^2$) is represented by following complexes:

- Complex of marl, marly clays and sands (L, LG, P), in which marls with inter-layers of marly clays, sand and sandy limestone dominate. Total thickness of the complex is 40 m. Its characteristic is laminar texture with slope of 5^o - 10^o.
- Complex of sands and gravels (P, S), which is represented by fine-grained sands and weakly sorted gravel, of rusty brown colour and strength of 15 m.
- Complex of limestone and sandstone (K_{CL}) with stratified texture. It is represented by sandy limestone - calcarenite and calcirudite and sandstone with carbonate to silicate binding. Total thickness of the complex is 20 m - 40 m.

Quaternary sediments build the largest part of terrain surface, with variable thickness from 5.0 m to 20.0 m. Within wider area of the collector, following lithogenetic types of sediments were separated:

- Fluvial - terrace sediments developed into 3 elevation levels: t_3 - the third terrace of Danube (H = 129 m - 140 m), t_2 - the second terrace of Danube (H = 86 m - 100 m) and t_1 - the first terrace of Danube (H = 74 m - 85 m);
- sediments of proluvial character - *pr*; deluvial sandy dust and dusty sands - *dpg*; deluvial-proluvial dust, sandy to clayey - *dpr*; loess deluvial sediments - *dl* and alluvial sediments - *a*.

In addition to the above mentioned, the complexes of clays, marls, sands and dusts were separated in surface parts of terrain on several locations within the explored area - the deposits of passive (*ku*) and active (*ka*) landslides. These landslides do not influence tunnel excavation. Their thickness is variable, over 10.0 m.

As particular complex, placed in the area of exit portal, complex of active landslides (*ka*) was separated and it is represented by mixture of clays, sand and dust. Minimal thickness of the landslide is 7 m - 9 m. They are placed in wider area of exit portal, along whole slope toward Dunavac.

3. ENGINEERING GEOLOGICAL PROPERTIES OF SEPARATED LITHOLOGICAL MEMBERS (COMPLEXES)

Table 1 - The results of investigation of uniaxial compressive strength

Drillhole mark Interval Rock type	Layer mark Age	Uniaxial compressive strength at natural humidity		Uniaxial compressive strength after moistening	
		Humidity w [%]	σ_c [MPa]	Humidity w [%]	σ_c' [MPa]
VI-3 27.3-27.4 Clayey marl	GL, LG Baden	19.99	3.501	26.05	1.325
VI-4 31.0-31.2 Clayey marl	GL, LG Baden	5.78	12.558	15.19	3.623
VP-5 31.0-31.2 Marly clay	LG Baden	20.31	0.749	29.05	0.255
VP-5 31.0-31.2 Marly sandy clay	LPG, L, Š Lower Miocene	12.82	1.966	18.03	0.503
VP-8 73.0-73.8 Sandstone, the basis of sandbar	K_{LG} Baden	13.93	1.174	19.96	0.846
VP-8 76.5-77.0 Sandstone, the basis of sandbar	K_{LG} Baden	15.77	2.519	17.14	2.078
VP-11 124.5-124.85 Gravel clay	ŠG Lower Miocene	8.89	4.348	13.08	0.911
VP-12 66.5-67.0 Tuffaceous clay	G, P Lower Miocene	10.39	3.237	18.23	1.101
VI-13i 45.5-46.8 Clay	G, P Lower Miocene	14.22	4.795	21.59	1.846
VI-14i 45.5-46.8 Clay	G, P Lower Miocene	13.53	1.386	28.14	0.413
VI-15 9.5-9.8 Clay	G, P Quaternary Ka	17.30	0.483	29.88	0.135

For separating engineering geological environments within the explored area, the properties of separated environments were the most significant. In the paper, authors presented geomechanical properties that serve as basis for classification: volumetric weight, uniaxial compressive strength, swelling strength, longitudinal elastic wave velocity. The results of investigation of uniaxial compressive strength at initial humidity and after moistening are presented in Table 1 (Majstorović and Cvetković, 2005). Separated environments have all characteristics of engineering geological complexes. In addition, in all lithogenetic complexes (members) that are of Neogene age and are represented by clays, deformable properties significantly decrease in the presence of water. Engineering geological properties of separated lithogenetic members (complexes) are presented according to superposition of the sediments that participate in geological structure of the explored part of terrain, beginning with the oldest.

3.1. Lower Miocene

Gravel clay complex (SG). They are characterized by frequent, relatively irregular change of marly clays, gravel marly clays, gravels and weakly tied conglomerates. Tickness of inter-layers and lenses is of dm-m dimensions. Tickness of complex exceeds 50 m. Clays that are very strong, weakly divided by cracks and splits (fissures), susceptible to swelling, prevail in the mass. Conglomerates are fine-grained to medium-grained, unequally cemented by marly-sandy binding.

Table 2 - Geomechanical properties of gravel clay complex

Geomechanical properties:			
Clays	$\gamma = 21.00 - 23.90$ kN/m^3	$\sigma_C = 4.348$ MPa	$v_p = 2{,}110 - 2{,}570$ m/s
Conglomerates	$\gamma = 22.64 - 22.44$ kN/m^3	$\sigma_C = 1.256$ MPa	$v_p = 1{,}380 - 1{,}630$ m/s
GN-200 classification: environment belongs to V category, conglomerates belong to IV category			

Clay and sand complex (G, P) - the colour is gray-blue, brown and dark red. Within these sediments, smaller inter-layers and lenses of dusty gray sands and weakly tied fine-grained conglomerates appear, as well as inter-layers of tuffaceous clays. Tickness of the complex is around 50 m.

Clays are characterized by massive texture, lumpy structure, presence of ferrous hydroxide. Cracks are frequent in the mass. Fissure systems are parallel, with slopes of $30^o - 45^o$ and $65^o - 70^o$, at the distance of 10 cm - 30 cm. Clays belong to the group of inorganic clays of high plasticity. They are characterized by solid state of consistency. Tuffaceous inter-layers have liquid limit $w_L = 160\%$ and plasticity index $Ip = 106\%$. Sediments of this complex are strong, well consolidated, practically incompressible, and susceptible to swelling. Due to humidity increasing, deformable properties decrease significantly.

Table 3 - Geomechanical properties of clay and sand complex

Geomechanical properties:			
$\gamma = 19.83 - 23.47$ kN/m^3	$\sigma_C = 1.386 - 4.795$ MPa	$\sigma_B = 942$ kPa	$v_p = 1{,}780 - 2{,}440$ m/s
GN-200 classification: environment belongs to IV-V category and for wet parts of environment (in the area of exit portal) III category is valid			

Clays, marly with tuffite (L, G, θ) - the colour is gray-green-orange-red. Inter-layers of tuffaceous material appear in complex. Environment is of massive texture, aggregate to lumpy structure. Tickness of complex is around 40 m. They belong to the group of inorganic clays of high plasticity, characterized by solid state of consistency and susceptible to swelling.

Table 4 - Geomechanical properties of clay, marly with tuffite

Geomechanical properties:			
γ = 20.42 - 23.60 kN/m^3	σ_C = 0.8 - 4.2 MPa	σ_B > 127 kPa	v_p = 2,290 - 2,380 m/s
GN-200 classification: environment belongs to IV category			

Clay with inter-layers of coal (G, U) - the colour is gray and brown. Clays, dusty sandy clays and dusty sands that appear cyclically represent it. Transitions between these intervals are gradual. Smaller inter-layers of coal, rarely peat, appear in these sediments. Tickness of complex is around 30 m.

Clay intervals are highly plastic (CH), characterized by solid state of consistency.

Dusty-clayey intervals are made of inorganic clays that have low to medium plasticity (CL-CI).

Dusty sands are tied, hard, well consolidated.

Table 5 - Geomechanical properties of clay with inter-layers of coal

Geomechanical properties:			
γ = 19.50 - 23.10 kN/m^3	σ_C = 2.8 - 3.5 MPa	σ_B = 100 - 450 kPa	v_p = 1,770 - 1,940 m/s
GN-200 classification: environment belongs to IV category			

Complex of marl and marly clays (L) - it is made of dusty sediments, of bright gray-green colour. Tickness of complex is around 70 m. Marls have massive to laminar texture. Lamination appears in two forms, in form of thicker laminae and thinner layers with gradual boundaries, or in form of fine laminae and layers with sharp boundaries. Laminae are thick 0.1 mm - 2 mm, rarely to 2 cm, along which they can be easily separated. Clays are of massive texture, dark brown to black colour, with rare inter-layers of gravel sand. They belong to the group of inorganic clays that have high plasticity (CH) and solid state of consistency.

Table 6 - Geomechanical properties of complex of marl and marly clays

Geomechanical properties:			
γ = 20.30 - 23.90 kN/m^3	σ_C = 2.94 MPa	σ_B = 196 - 290 kPa	v_p = 1,490 - 1,820 m/s
GN-200 classification: environment belongs to IV category			

Complex of marly sandy tuffaceous clays and marls (LPG, L, θ) - the colour is gray green, rarely dark red. It is characterized by lens-like to stratified texture. Clastic sediments – gravel and conglomerates appear in form of thinner inter-layers. Conglomerates are weakly tied by marly-sandy binding. Clays and marls have massive texture. Clays are of montmorillonite structure, highly plastic and susceptible to swelling. In intermediate roof parts of complex, inter-layers of tuffites with high liquid limits ($w_L = 130\% - 150\%$) appear. Tickness of these inter-layers, according to documentation, is 2 m - 4 m. Tuffite is thixotropic and hygroscopic, unstable in contact with the air. Its hardness is little and it is very susceptible to swelling.

Table 7 - Geomechanical properties of complex of marly sandy tuffaceous clays and marls

Geomechanical properties:			
$\gamma = 21.00 - 22.80$ kN/m^3	$\sigma_C = 0.5 - 3.4$ MPa	$\sigma_B = 350$ kPa	$v_p = 2{,}060 - 2{,}790$ m/s
GN-200 classification: environment belongs to IV category			

Complex of marly-sandy clays and marls with gravels (LPG, L, S) - clays mostly have rusty red colour, massive texture and solid state of consistency ($Ic = 1.5$) and they are susceptible to swelling. Gravel of different petrographic composition (limestone, chert, serpentinite, quartz, tuff and tuffite) and fine-grained sand appear in them. Gravels are half-round to round and size of grain is up to 1 cm. Lenses and inter-layers of gravel represent zones of accumulation and filtration of water through this environment.

Table 8 - Geomechanical properties of complex of marly-sandy clays and marls with gravels

Geomechanical properties:			
$\gamma = 20.90 - 23.80$ kN/m^3	$\sigma_C = 1.5 - 7.0$ MPa	$\sigma_B = 492$ kPa	$v_p = 2{,}180 - 2{,}240$ m/s
GN-200 classification: environment belongs to IV-V category			

3.1. Baden

Complex of basal conglomerates (KG, PS) - it is represented by sands and sandstones that have green colour in intermediate roof part while in shelf parts, dark gray to black conglomerates, weakly tied black sands, sandstones and limestones appear. Roof sands and sandstones are in sub-horizontal forming in layers (inter-layers). Sand is clayey to dusty, weakly tied, fine-grained and compact (compressed). Sandstones are weakly to well petrified and conglomeratic in places. Shelf conglomerates are tied by marly-clayey binding and limestones are sandy. Sands are clayey. Gravels are coarse-grained (7 cm - 8 cm) and angular. They are mainly made of sandstone and limestone. In open excavation, unstableness of excavation sides may occur.

Table 9 - Geomechanical properties of complex of basal conglomerates

Geomechanical properties (weakly tied sandstones):		
$\gamma = 20.65$ kN/m^3	$\sigma_C = 1.17$ MPa	$v_p = 1{,}550$ m/s
GN-200 classification: environment belongs to IV category		

Marly-sandy clays (LG, GPL) - they have dark green colour and variable thickness of 10 m - 20 m. Their characteristic is massive texture and shell-like fracture. Inter-layers of white marlstones that are thick 2 cm - 5 cm appear in mass. Clays and marls are dusty to sandy. Environment is hard, breakable, highly plastic (CH) and susceptible to swelling.

Table 10 - Geomechanical properties of marly-sandy clays

Geomechanical properties:			
$\gamma = 20.30 - 21.15\ kN/m^3$	$\sigma_C = 1.42\ MPa$	$\sigma_B = 369\ kPa$	$v_p = 960\ m/s$
GN-200 classification: environment belongs to III-IV category			

Carbonate marly-clayey complex – the basis of sandbar (K_{LG}) - it appears in shelf of sandbar organogenetic litotamnium limestone. Total thickness of complex is not determined and exceeds 30.0 m. Environment is built mainly of algae litotamnium that are tied by carbonate, clayey and marly binding. The colour is gray to palely gray. Cracks are squeezed and have rough surface. Environment is characterized by frequent change of binding that can be at 20 cm - 30 cm, more often at 50 cm. Characteristics of this complex depend on dominant binding in mass. In the area of calotte of tunnel, degradation of complex was noticed. Presence and oscillating of underground waters in this area affects dissolving and softening the sediments of the basis of sandbar. Sediments have variable deformable and filtering characteristics.

Table 11 - Geomechanical properties of carbonate marly-clayey complex

Geomechanical properties (weakly tied sandstones):		
$\gamma = 19.10 - 25.40\ kN/m^3$	$\sigma_C = 1.53 - 6.48\ MPa$	$v_p = 1{,}260 - 3{,}140\ m/s$
GN-200 classification: environment belongs to IV-V category		

Sandstones (PS) - they appear at the edges of the basis of sandbar. They represent gradual transition between marly clays and clayey marls (GL, LG) and the basis of sandbar (K_{LG}). Sandstones are of greenish colour, they are weakly petrified to petrified. Their characteristic is large percentage of fossils in mass. They are fine-grained, of massive texture, without notable cracks and fissures. They are marly to clayey in places, well tied and practically impermeable to water.

Table 12 - Geomechanical properties of sandstones

Geomechanical properties (weakly tied sandstones):		
$\gamma = 19.81 - 22.40\ kN/m^3$	$\sigma_C = 0.85 - 1.17\ MPa$	$v_p = 1{,}500 - 1{,}840\ m/s$
GN-200 classification: environment belongs to III-IV category		

Limestone (K_L) - they are organogenetic, sandbar, and have yellowish colour. Tickness of limestone is around 70 m. Litotamnia algae prevail in mass and fossils of shells and snails (conus, ostrea) frequently appear and their size is 5 cm - 10 cm. Within limestone, there are inter-layers and lenses of marly clays and marls. Limestones are quite fragile, weakly cemented and cracked. They are taken by carstification process so they are unequally carstificated, with caverns of different dimensions, frequently filled with dusty-sandy filling.

Table 13 - Geomechanical properties of limestone

Geomechanical properties (weakly tied sandstones):		
γ = 19.10 - 19.50 kN/m^3	σ_C = 2.078 MPa	v_p = 1,340 - 1,420 m/s
GN-200 classification: environment belongs to IV-V category		

Marly clays and clayey marls (GL, LG) - the colour is dark brown to ash gray and gray-green. They have massive texture and shell-like fracture. Their characteristic is variable presence of carbonates in mass. Marlstones appear in form of rare layers that are thick 20 cm - 30 cm. They are of whitish colour, strong and compact. They belong to the group of inorganic clays of high plasticity (CH) and of hard to solid state of consistency. Environment is hard, well compressed and compact. Clays and marls are susceptible to volumetric changes. They are changed physically and chemically on the places of contact with limestones. Contact zones with sediments that are impermeable to water are wet and have reduced strength parameters. In them, one should expect glueing with tools.

Table 14 - Geomechanical properties of marly clays and clayey marls

Geomechanical properties:				
Marls	γ = 19.23 - 22.07 kN/m^3	σ_C = 3.50 MPa	σ_B = 430 - 850 kPa	v_p = 1,780 - 2,190 m/s
Marlstone	γ = 25.32 kN/m^3	σ_C = 12.56 MPa		v_p = 2,130 m/s
GN-200 classification: environment belongs to IV category, conglomerates to V category				

Marly clays (L, G), marls, marly clay and sands (L, LG, P), complex of sands and gravels (P, S), complex of limestone and sandstone, marlstone (K_{CL}) represent environments that are not going to be engaged in tunnel excavation so their engineering geological properties are not presented.

3.2. Quaternary

Complex of dusts of sand and clays Ka - represents active landslide in the area of exit portal and its depth is around 6 m - 8 m. Depth of sliding in middle and upper parts of slope is up to 20 m. However, this fact does not have particular importance, as it is located out of influence zone of building (out of calotte of tunnel). Their resistance characteristics are reduced to residual values. Clays have tendency to volumetric changes and wetting by water that infiltrates the environment through sand inter-layers. Additional reasons for sliding are oscillations of Danube and Dunavac water that contribute to destruction of sediments by filtration and reduce stability of an already unstable slope. In open excavation, it is completely unstable, with occurence of mass flowing and falling out of monoliths of various dimensions, swelling and possible development of large underground pressures.

Table 15 - Geomechanical properties of complex of dusts of sand and clays

Geomechanical properties:			
γ = 19.00 - 21.26 kN/m^3	σ_C = 0.64 MPa	σ_B = 85 kPa	v_p = 1,790 - 1,870 m/s
GN-200 classification: environment belongs to III category			

4. GEOTECHNICAL ZONING OF TERRAIN ALONG TUNNEL AXIS

Geotechnical zoning of terrain in the area of tunnel excavation was done in order to define geotechnical conditions for building, based on lithological structure of separated lithological complexes, thickness of super-layer, resistant-deformable properties of separated environments and the possibility of water occurrence in excavation.

Categorization for purpose of defining geotechnical conditions for tunnel construction (categories A, B, C and D) was done according to data that are obtained based on available investigations. Categorization for excavation was performed by method of hydro-shield. Geotechnical categories are separated in exceptionally heterogenous conditions so the characteristics of separated categories are within wide range of physical and mechanical properties.

Geotechnical category "A" includes sediments of carbonate marly complex of sandbar base (K_{LG}), organogenetic sandbar limestones (KL) and sandstones (PS). At finish grade level of tunnel, they are present in length of around 1000.0 m. According to GN-200 classification, environment belongs to IV-V category.

Limestones are with inter-layers and lenses of marly clays and marls. They are massive, fragile, weakly cemented, of spongy porousness, cracked to cavernous. Cracks are squeezed, rough and without traces of moving.

Sandstones are fine-grained, with carbonate marly binding and weakly petrified. They are of massive texture and weakly cracked. In this environment, there is discontinuous aquifer with variable level of water. During excavation, affluence of underground water, by dripping and leaking, from cracked cavernous parts of limestone, is expected. Inflows of water of 80 l/h/m - 300 l/h/m may occur from time to time.

Geotechnical category "B" includes sediments of clayey-marly complex (GL, LG) that are present in two intervals of 340.0 m and 900.0 m, marls (L) in length of 350.0 m, gravel clays (SG), marly clays with tuffite (LG, θ) and clays with sand (G, P) in length of 2100.0 m. According to GN-200 standards, rock masses of the environment belong to IV-V category.

Sediments of marly-clayey complex (GL, LG) are of massive, rarely laminar, texture. They have tendency to divide along existing squeezed cracks and ss-surfaces when humidity is reduced. Environment is disposed to swelling.

Complex of marl (L) has stratified to laminar texture. Marls are very strong and their swelling is less. They divide along existing cracks and ss-surfaces while drying.

Complex of sediments of "multicoloured series" (LG, θ), (G, P), (SG) is characterized by changeable lithological structure, heterogenous resistant-deformable properties and great tendency to swelling ($\sigma_B = 400$ kPa - 1000 kPa).

Geotechnical category "C" includes clastic sediments within following complexes: marly-sandy tuffaceous clays and marls (LPG, L, θ), marly-sandy clays and marls with gravels (LPG, L, S) and basal conglomerates (KG, PS) and marly-sandy clays from complex (LG, GPL). Environment comprise route in length of 430.0 m.

According to GN-200 standards, rock masses of the environment belong to III category and in less part to IV and V category.

Complex of marly-sandy clays (LG,GPL) is of massive texture, with slightly expressed crack systems, and in hydro-geological respect, it is practically impermeable to water.

Clays and marls, with thinner inter-layers or lenses of gravels and sands, or weakly tied conglomerates and sandstones (LPG, L, θ), (LPG, L, S) are of massive texture, they are divided by rare sub-vertical cracks. Sediments are very solid, well consolidated, highly plastic and susceptible to swelling.

Clastic sediments appear as separate member (KG, PS) or in form of thinner inter-layers or lenses of gravels and sands or weakly tied conglomerates and sandstones. Inter-layers and lenses have variable thickness, decimetrical to metrical. In lenses and inter-layers of gravels and sands, significant quantities of underground water may accumulate and if they are mutually connected, water in excavation will occur from them. Expected quantity of water from layer (KG, PS) is 100 l/h/m under pressure that exceeds 1.2 MPa.

This geotechnical category is, to a great extent, characterized by the problem of excavation instability due to lack of strength and cohesion, swelling occurrence, material stickiness, water occurrence by dripping, as well as exposure to hydro-static pressures (≥1.2 MPa).

Figure 2 shows schematic display of geotechnical categories along the "Višnjica" tunnel.

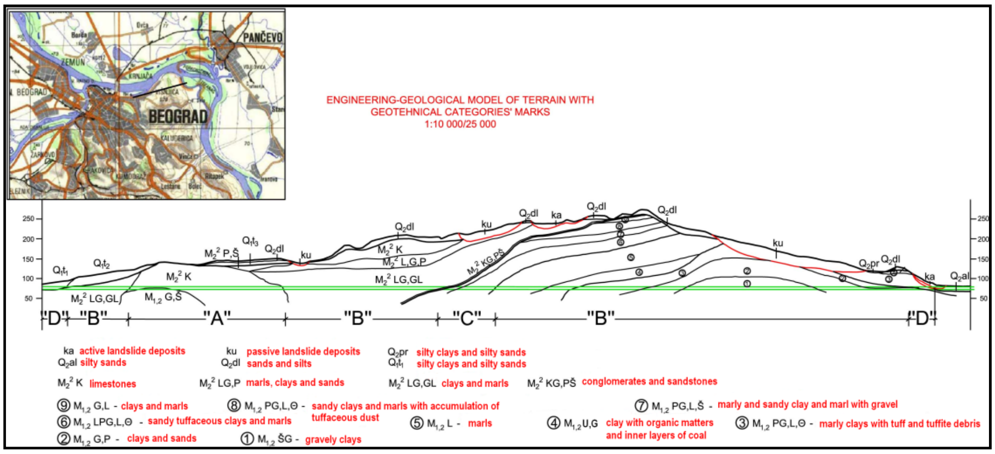

Figure 2 - Schematic display of geotechnical categories along the "Višnjica" tunnel (Vukadinović, 2006)

Geotechnical category "D" - within this geotechnical category, terrace PPRt$_1$ and proluvial deposits (PPR, S), marly clays (LG) in the zone of surface area changes, and clays with inter-layers of coal (U, G), are represented in several sections of an overall length of 570.0 m. According to GN–200 standards, rock masses of this environment belong to category III, and to lesser extent to categories II and IV.

Terrace $PPRt_1$ and proluvial (PPR, S) are the deposits of dusty clay composition with pebbles of gravel that dominates in the shelf part of these deposits. Environment is compressible, saturated with water, poorly permeable to water. The first aquifer is formed in them. The waters of this aquifer shall occur during the construction of excavation with a possible flow of 8 l/h/m - 24 l/h/m. Marly clays (LG) are partially degraded by processes of surface decay. They are of massive texture and divided to smaller monoliths (of mm - cm dimensions) by fissures and cracks. Environment is well consolidated, of high plasticity and susceptible to swelling; however, the values of swelling are small in comparison to other sections (around 200 kPa). Since the environment is dipping directly under the Quaternary deposits, from which the surface waters are being drained, the environment is saturated with water. The sediments are characterized by a small uniaxial compressive strength (<1.0 MPa).

The clays with the inter-layers of coal (U, G) are represented by dusty clays and dusty sands that are alternating cyclically and thinner inter-layers of coal occur in the series. Clayey sediments are consolidated, of strong consistency state, of high plasticity and susceptible to swelling. Uniaxial compressive strength, obtained in laboratory conditions, showed wide range of 0.15 Mpa - 3.5 MPa. Their texture is massive and rare cracks can be observed. Dusty sands are partially bound and well consolidated. Their water permeability is low to medium and they represent zones of accumulating and draining of waters. In the surface area, in the zone of exit portal, up to depth of 7.0 m, the sliding process (Ka) affects them. In the upper parts of the slope, this process is quick while in the lower part, it has slower character. Thickness of the upper layer in the exit part of portal varies from 0 m to 8.0 m.

5. CONCLUSION

Based on geotechnical zoning of terrain in the area of tunnel excavation, it was concluded that all four categories of excavation, according to their characteristics, require the application of hydro-shield method. Application of the method meant building of the excavation that has circular shape, with external radius of 4.60 m and internal radius of 4.10 m. Machine construction enables performance in different geological and geotechnical conditions, in instable and humid environments, regardless the form and quantity of underground water. Investigations that were conducted on representatives, particularly at humidity increasing, shown that this method application is necessary.

21.11.2012, after three years of intensive work, tunnel "Višnjica" is successfully built. During the works, 125,000 m^3 of soil were excavated, 25,000 m^3 of concrete were built on and 28,380 pieces of segment were set.

ACKNOWLEDGEMENT

This paper was realized as a part of the project "Geotechnical aspect of research and development of a modern technology in the construction and maintenance of municipal waste deposits" (TR 36014) and the project "Improvement of lignite opencast mining technology in order to increase energy efficiency and occupational safety" (TR 33039) financed by the Ministry of Education, Science and Techonological Development of the Republic of Serbia within the framework of Programme of research in the field of technological development for the period 2011-2014.

REFERENCES

[1] MAJSTOROVIĆ, J. and CVETKOVIĆ, M. (2005) *Report on investigation results of physical and mechanical properties of representatives separated from explored drillholes on the route of tunnel "Višnjica"*. Belgrade: Faculty of Mining and Geology.

[2] VUKADINOVIĆ, I. (2005) *Preliminary project Interceptor Ušće - Veliko Selo, section of the tunnel "Višnjica" - CS "Veliko Selo", from km 6+800 to km 12+639, volume 1/1*. Belgrade: Geotecnical foundation, GIS documentation fund.

[3] VUKADINOVIĆ, I. (2006) *Main project Interceptor Ušće - Veliko Selo, section of tunnel "Višnjica" - CS "Veliko Selo", from km 6+800 to km 12+639, volume 1/1*. Belgrade: Geotecnical foundation, GIS documentation fund.