Client:	Správa železniční dopravní cesty, s.o.
	Dlážděná 1003/7
	110 00 Prague 1
Contractor:	SUDOP PRAHA a.s.
	Centre 207 Geotechnics
	Olšanská 1a, 130 80 Prague 3
Project name:	Modernisation of Prague-Výstaviště (except) – Prague-Veleslavín (except) track
Order number:	18-211.207

MODERNISATION OF PRAGUE-VÝSTAVIŠTĚ (EXCEPT) – PRAGUE-VELESLAVÍN (EXCEPT) TRACK

SO 06-25-01 Mined tunnel left
SO 06-25-02 Mined tunnel right
SO 06-25-04 Air shaft Střešovice

Geotechnical Investigation
Variant CENTRE

Responsible task manager
of geological works: RNDr. František Dragoun

Prague, June 2020

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1. BASIC DATA

Project name: Modernisation of Prague-Výstaviště (except) – Prague-Veleslavín (except) track

Characteristic of construction: The section of railway track Prague-Bubny – Rakovník, route section Prague-Bubny – Chomutov (0101), definition section Prague-Bubny – Prague-Dejvice (0101 02), railway st. Prague-Dejvice (0101 B1), Prague-Dejvice – Prague-Veleslavín (0101 04) is the construction location. This construction is part of construction set "Rail link between Prague, Ruzyně Airport, and Kladno". Adding one track, increasing the speed due to route modifications, improving the rail link between Prague and Kladno, servicing V. Havla Airport in Ruzyně, removing effect of the construction and negative impact of railway operation on track surroundings, increasing security, improving the combination of railway and urban public transport are aims of the construction.

Purpose of exploration: Developing the preliminary geotechnical exploration and determining geotechnical properties of rock environment for needs of processing construction project were purposes of works.

The extent and nature of exploration work of geotechnical exploration was set up based on requirements of expert designers of the construction. The location and number of boreholes respected the requirements of Metroprojekt a.s. designer.

The original location of exploration wells carried out in Aug. 2018 was based on the original track routing VARIANT V4. The variant was changed within consultations. The routing of tunnels in VARIANT V5 was submitted for debate (Feb. 2019). Based on the debate of action, the routing was modified (moved) at the exit portal, opposite to the chainage direction of mined tunnel to the area of crossing of streets Milady Horákové and Svatovítská – chainage approximately km 4.130 approx. Negative impacts on "Ořechovka" site and on Institute of Physics of the Czech Academy of Sciences were eliminated due to the partial change of route.

The alternative variant "Centre" was chosen because of negative attitude of local public with the routing of the future structure in the south part of defined corridor. Entrance and exit portals of tunnels remain in the original position, the horizontal alignment of tunnels changes only. Tunnel structures pass approximately in parallel under Střešovická and Na Petřinách streets.

This report adds boreholes carried out newly in the section of construction and the change of its horizontal alignment – area of entrance portal to the original report of Aug. 2019. Due to the complexity of exploration works, boreholes, laboratory and technical reports, and explorations from the original stage of exploration works of Feb. 2019 are also left in the report. **The original report dated Feb. 2019 on GT exploration of Střešovice mined tunnels was prepared by company PUDIS a.s., Nad Vodovodem 2/3258, Prague 10 (R. Chmelař, P. Tůma).** Therefore, the information obtained provides collective and coherent knowledge on geological and hydrogeological structure in the area of interest allowing to choose an optimum variant of tunnel structures.

1.1. DESIGN DOCUMENTS USED

Necessary documents, i.e. the layout and the longitudinal section in electronic form, were handed over to contractors during order fulfilment. The layout and longitudinal and transverse sections of Variant V4 were used as the starting point first. After carrying out drilling works in Feb. 2019, the layout, the longitudinal section of the left mined tunnel SO 06-25-02, and transverse sections in the routing of Variant V5 were available that differed from the routing of Variant V4 in the area of Institute of Physics of the Czech Academy of Sciences. The route was moved towards the south by max. 0.270 km approx. in the area of Institute of Physics of the Czech Academy of Sciences respectively in the area of “Ořechovka” and the mined part of the tunnel was prolonged by approx. 0.450 km – Variant 08/2019 (variant “South”) after the debate. The entrance portals of mined tunnels are located in the area of streets Svatovítská and Milady Horákové crossing (Prašný most) in the variant “Centre” – identical with variant “South”. The track routing differs behind the Střešovice tram depot as compared with the previous variant (08/2019 – South). The route passes approximately in parallel under Střešovická and Na Petřinách streets. The passage of tunnels under the local villa and residential houses is minimised by this routing.

The objects of mined tunnel Střešovice are given in the following table.

Tab. No. 1.1.a: Division of building structures

Building structure of mined tunnel		
SO 06-25-01	Mined left tunnel Střešovice	km 4.215-7.322 (length of 3.107
SO 06-25-02	Mined right tunnel Střešovice	km 4.200-7.305 (length of 3.105
SO 06-25-03	Cross passages Střešovice	see the layout drawing
SO 06-25-04	Střešovice technological structure	km 5.598
Length of mined tunnels in total (m)		6 212

Tunnel structures will be carried out as mined using the TBM method in all cases, tunnel passages and the air shaft will be mined using the NATM method.

1.2. NORMATIVE DOCUMENTS

In previous explorations, soils were classified according to standard ČSN 73 1001 that is invalid now. Newly dug boreholes are classified according to ČSN 73 6133 and ČSN P 73 1005 that are valid currently and take over marking from the original standard generally. Soils of new boreholes are classified also according to ČSN EN ISO 14688.

The situation is complicated also in case of evaluating workability. In archive explorations, the classification according to ČSN 73 3050 was applied that is invalid now. Nowadays, the workability is classified according to ČSN 73 6133 and ČSN P 73 1005 that have quite a different principle of breakdown. The workability of rock environment was evaluated according to both mentioned standards in the exploration.

2. METHODOLOGY AND EXTENT OF EXPLORATION WORK

The following survey methods were applied in the carried out geotechnical investigation for mined tunnels in the framework of Prague-Exhibition Grounds - Prague-Veleslavín line modernisation:

- Archive investigation
- Field engineering-geological works (boreholes and taking samples)
- Laboratory tests
- Field tests (pressiometric and dilatometric measuring)
- Hydrogeological work
- Logging measurement
- Vibration measuring

2.1. FIELD ENGINEERING-GEOLOGICAL WORKS (BOREHOLES AND TAKING SAMPLES)

Newly carried out boreholes supplemented by archive exploration works, knowledge gained by a survey in the field at personal visits of the area, and studying available literature were basic sources of determining the geological structure of the area. Descriptions of new boreholes together with archive boreholes are given in a separate Annex. Summary overview of exploration works carried out is given in following Table No. 2.

16 exploration boreholes of 860.7 m total length were carried out newly in the scope of GTE from the terrain surface for variants taken into consideration. Two boreholes marked HJ15 and HJ16 were carried out newly for the variant “Centre”. Real positions of individual wells follow from the attached layout of exploration wells (Annex No. 1) and from tabular summary of works above.

The extent of works was based on requirements of responsible designers of the construction, financial means, and accessibility of terrain for technique of drilling wells mainly.

Carrying out exploration works was preceded by reconnaissance of the terrain to find out that there were no intervention to the surface in the area of interest. Archive sources – Czech Geological Service - Geofond Prague, the archive of PUDIS a.s. Company were examined, too.

Overview of carried out works according to the timing:

1. legal steps related to permission, resp. notification of exploration works
2. verification of underground lines and ensuring written contracts on entrance and compensation of damage with owners of plots
3. drilling works – engineering-geological, hydrogeological, dilatometric, and pressiometric boreholes
4. the documentation, the photographic documentation of borehole cores, taking laboratory samples
5. pressiometric and dilatometric measuring in boreholes

6. pumping tests in hydrogeological boreholes
7. disposal of borehole core
8. regulation for laboratory tests their carrying out
9. hydrogeological evaluation of area
10. certification of water source affected by sinking
11. analysis of gained field and laboratory data
12. processing the report on exploration
13. submitting the report on exploration for comments
14. integrating comments and handing over the fair copy

Newly carried out HJ1 – PJ9, HJ11 – J16 exploration wells are listed in following tables (SUDOP PRAHA, a.s. – Nov. 2018 - Jan. 2019, June 2019, April/2020).

Table No. 2.1.a: Overview of drilling and laboratory works

Object	Borehole depth (m) actual/design	Chainage (km)	Samples (pcs)									Y - JTSK	X - JTSK	Z – Bpv a.s.l.
			Sd	Rm *	V	Ud	Pe	Abr	Si	Ca	Sw			
HJ1	40.00 / 40.00	4.616	5	2	1	2	1	1	1	1	1	744811.023	1041726.996	240.709
PJ2	40.00 / 40.00	4.670	5	1	-	2	-	-	1	-	-	744866.257	1041689.966	240.703
J3	56.00 / 56.50	5.168	1	6	1	-	1	1	-	-	-	745341.937	1041740.292	268.740
HPJ4	60.00 / 60.00	5.161	2	8	-	-	2	2	-	-	-	745330.883	1041818.144	270.948
J4a	10.00 / 10.00	5.143	-	-	-	-	-	-	-	-	-	745323.780	1041818.585	270.771
J5	51.00 / 51.00	5.118	1	6	1	-	-	-	-	-	-	745283.016	1041922.033	276.104
J6	72.00 / 72.00	5.594	1	8	1	-	-	-	-	-	-	745734.965	1041959.976	294.058
PJ7	94.30 / 94.00	6.094	1	8	1	-	1	-	-	-	-	746230.700	1042098.336	335.275
HJ8	31.00 / 31.00	7.257	2	8	1	1	-	-	-	-	-	747375.130	1 041775.166	305.650
PJ9	34.00 / 34.00	7.302	2	5	1	1	1	1	-	-	-	747317.602	1 041790.772	302.452
HJ11	92.00 / 92.00	6.578	-	8	1	-	-	1	-	-	-	746717.704	1042120.813	349.413
HPJ12	32.00 / 32.00	4.216	4	-	1	4	-	-	-	-	-	744378.75	1041887.82	240.97
PJ13	36.00 / 35.00	4.329	2	-	-	4	-	-	-	1	-	744493.06	1041905.52	241.66
J14	64.00 / 64.00	4.936	-	6	-	-	1	2	-	-	-	745086.69	1042032.16	276.15
HJ15	58.40 / 58.00	6.112	-	10	1	-	4	3	-	-	-	746 255.07	1041903.84	301.50
HJ16	90.00 / 90.00	6.673	-	9	1	-	2	3	-	-	-	746814.58	1042013.56	346.50

Object	Borehole depth (m) actual/design	Chainage (km)	Samples (pcs)									Y - JTSK	X - JTSK	Z – Bpv a.s.l.
			Sd	Rm*	V	Ud	Pe	Abr	Si	Ca	Sw			
16 pcs	860.70 / 859.00	-	26	85	11	14	13	14	2	2	1	-	-	-

Legend:

Samples – Sd – semi-disrupted, Rm* – rock mass, Wa – groundwater/aggressivity of solid environment, Ud – undisrupted, Pe – petrographic analysis, Abr – abrasiveness, Si – sinkability, Ca – carbonates, Sw – swelling capacity

** rock set samples were taken in case of rock samples, that is the number does not mean one sample but one rock set.*

2.2. DRILLING WORKS

Drilling works were carried out depending on permits of respective administrative offices (City District Prague 6, Technical Management of Roads) progressively in three main phases. designed and actually carried out lengths of boreholes are summarized clearly in the Table 3.1 above. 16 boreholes of 860.70 m total length were carried out for mined tunnel structures in all phases.

Drilling works were carried out in two phases:

1. phase – deadline 19 Nov. – 18 Dec. 2018 – J6, PJ7, PJ8, HJ9 boreholes
2. phase – deadline 16 Jan. – 17 Jan. 2019 – J10 borehole
3. phase – deadline 17 June – 28 June 2019 – HPJ12, PJ13, and J14 boreholes
4. phase – deadline 20 April – 07 May 2020 – HJ15 and HJ16 boreholes

Technology of drilling works

Stavební geologie - IGHG Tachlovice s.r.o. drilling company carried out exploration boreholes using drilling rig of ADBS/Mercedes Atego type, SUDOP a.s. company decided to use RDBS drilling rig on the caterpillar undercarriage because of poor terrain accessibility of terrain in case of J6 borehole. J10, HPJ12, PJ12 wells were carried out using Wirth B1/PV3S and UGB1/PV3S drilling rigs. Core and full-core drilling were applied as drilling technologies.

As foreseen, part of the survey boreholes was carried out in resistant rock masses using a diamond drilling tool and water flush.

Drilling advance boreholes

Introductory parts of boreholes (i.e. quarter sediment, heavily weathered underlying rock masses) were drilled using a simple core drill fitted with pen-like bits (hereinafter SCDPLB) of 195 mm cutting diameter up to the depth of encountering relatively solid underlying rock masses. All drilling was carried out without using drilling flush, i.e. in a dry way. HJ1, PJ2, HPJ12 and PJ13 boreholes were carried out using a simple core drill over their entire lengths because thick quarternary sediments (loesses, loess-like loams, fluvial terrace sediments) and strongly degraded top zones of weathered rock subbase were present.

Drilling to the final depth

With regard to the required yield and quality of borehole core, boreholes were drilled to the final depth using double Craelius WL-NQ core drill with internal core barrel workable on a rope, fitted with diamond drilling bits (hereinafter WL-NQ Dia) of 76 mm cutting diameter. Water drilling flush was used at drilling. Boreholes drilled finally in this way were cased in the section of advance boreholes using additional string of 89 mm diameter casings for tighter guiding of WL-NQ drilling string in the course of work with the aim to prevent the emergence of vibrations and to provide for maximum yield and quality of borehole core.

Lengths of individual core runs and times needed for their implementation were recorded in sections drilled using Dia technology in the course of drilling works. Borehole cores were placed to standard V2 and V7 sample containers.

After carrying out sampling and documentation works, boreholes were disposed of by plugging cement mixture and by back-filling extracted material in the upper part.

Monitoring boreholes – HJ8

With respect to the required equipment (PE 125 mm diameter), it was designed to enlarge the referred to core boreholes finally drilled using Dia of 76 mm diameter to the diameter corresponding to the equipment. Boreholes were enlarged by full-core drilling using submersible pneumatic hammer.

The introductory part was core drilled, SCDPLB in 220 mm cutting diameter. All drilling without drilling flush, i.e. in a dry way. The advance borehole prepared in this way was cased using protective technical string. The final depth was reached by full-core drilling using submersible pneumatic hammer in 6.5“ (approx. 165 mm) cutting diameter. Compressed air was used for drilling.

It was not necessary to reprofile HJ1 and HPJ12 boreholes using submersible hammer for reasons of geologic conditions found.

Equipment of boreholes

Boreholes were equipped definitively with PE HD pressure casing (screen) of 125 mm diameter, Js 2.0 mm. The positioning of perforated and full part of equipment, packing, and plugging is given in the Annex of Summary Report. The perforation of equipment is drilled with boreholes of 3 mm inner diameter, the area of perforation in the performed area amounts to approx. approximately 8-10 %. The performed area of equipment was packed with washed aggregate of 4-8 mm grain size (sand pit Dobříň). The full part of equipment was packed with ground clay and granulated packing bentonite TSB.

Boreholes HJ11, HJ15 and HJ16 were equipped with PVC casing of 63 mm diameter, Js 58.6 mm, without packing from washed aggregate. It was not possible to equip boreholes in their full length with respect to the low stability of walls.

Cast iron slide valve cover mounted to the depth of 0.5 m approx. in the concrete collar, with the upper edge at ground level (trafficable head) make up the protective head of HJ1, HJ8, HJ15, and HJ16 boreholes.

Steel casing pipe of 168 mm diameter mounted to the depth of 0.5 m under ground level in the concrete collar, with the upper edge 0.5 m above ground level make up the protective head of HPJ12 boreholes. The mouth of casing pipe was closed using steel swivel-cover.

2.3. GEODESIC SURVEYING

Individual drilled geological wells were surveyed using GNSS of grade 3 accuracy and GNSS apparatus of serial number LEICA CS 10 Dwg. No. 2525063. Physical reductions (temperature, pressure) were introduced at the measuring.

Wells were surveyed in compliance with acts, orders, and decrees below:

- Act No. 200/1994 Coll. on Surveying
- Decree No. 31/1995 Coll.,
- Decree Implementing Act No. 200/1994 Coll.,
- Government Decree No. 430/2006 Coll. on Defining Geodetic Reference Systems and State Map Series Obligatory for the Whole State Territory and Principles of their Usage.

2.4. PRESSIOMETRIC MEASURING

In the preliminary GTE scope, 34 pressiometric tests in total were carried out in PJ2, HPJ4, PJ7 PJ9, HPJ12 and PJ13 boreholes for all phases. Pressiometric tests on unsupported walls in core boreholes of 76 mm diameter were carried out using a pressiometric apparatus made by French company MÉNARD of GA type with 8 Mpa range of radial pressure and a well of NX type with 74 mm diameter. Pressiometric tests took turns with drilling of individual levels due to the necessity of maintaining undisrupted borehole walls.

The methodical procedure and evaluation of tests were in compliance with rules for a standard pressiometric test as outlined in French originals and ČSN 72 1004. Volume deformations were read after 15, 30 and 60 seconds. Pressure and volume losses of the instrument were compensated according to calibration curves in the evaluation.

The pressiometric static deformation modulus $E_{def,p,}$ is the most important test result that is determined always from the linear pseudoelastic phase of deformation diagram, i.e. as the maximum value of all static deformation moduli in the whole field of induced stress. All tests were carried out in rock masses of upper Paleozoic layer, in siltstones (9 pcs in total), sandstones (8 pcs in total), cobblestones (6 pcs in total), and tuffs (1 pc) specifically. The rock masses were divided to fully, heavily, slightly weathered, and to weakly weathered further based on measuring results. Average pressiometric static deformation moduli $E_{def,p}$ were determined for individual types of rock masses.

Frequently, the measured values of static deformation moduli $E_{def,p}$ are influenced by irregular occurrences of more solid or softer locations on the contrary in the measured section. Pressiometric measuring provided thus higher values, even abnormal values locally in most cases. Abnormal values were not taken into account at setting GT parameters. Detailed results of pressiometric measuring are listed in the Annex No. 9 of this report.

2.5. DILATOMETRIC MEASURING

In the GTE scope, dilatometric measuring was carried out at boreholes J14, HJ15, and HJ16. At 7 levels in total at J14, the measurements were carried out at three levels at boreholes HJ15 and HJ16. Dilatometric tests (sometimes referred to as rock pressiometer tests) on unsupported walls in core boreholes of 76 mm diameter were carried out using PROBEX well made by Canadian manufacturer ROCTEST. Measuring membrane of 73.7 mm diameter and of 457 mm effective length is reinforced with glass fibres to achieve higher resistance. A coaxial line connects the exploration well of 290 cm total length (pressure hose + data cable) with the hydraulic pump and the evaluation unit. The dilatometric exploration well is lowered to the borehole on a set of rods, the operator pressurised the flexible measuring membrane using the hydraulic pump up to the maximum pressure of 30 MPa then (max. pressure reached depends on the nature of rock material) that is transmitted to borehole walls radially. Measured data is transmitted to the recording and evaluating unit on the surface.

The methodical procedure, the evaluation, and the application of dilatometric test results are accurately described by the manufacturer, who proceeded on requirements of ISRM (Suggested Method for Deformability Determination Using a Flexible Dilatometer – 1987) at designing the instruments and procedures. The tests were carried out using controlled stress that was increased step by step and in depth intervals of 1.5 - 5.0 m ideally (the minimum distance between individual measuring levels amounts to 1.5 m). The dilatometric modulus Ed is the essential output characteristic. It is calculated from the diagram of dependence of volume of pushed in liquid on its pressure according to relation

$$E_d = (1 + \nu) * (V_o + V_m) *\left(\frac{1}{\frac{\Delta V}{\Delta Pb} - c} \right)$$

where

V_o ... theoretical volume of measuring part of drained well (the value gained from calibration)

V_m ... the difference $\frac{V2-v1}{2}$ from linear section of curve selected to determine E_d

ΔV ... difference $V_2 - V_1$ from linear section of curve selected to determine E_d

ΔP_b ... difference $P_{b2} - P_{b1}$ from linear section of curve selected to determine E_d

c ... calibration constant gained from volume calibration

Compared to common pressiometric tests (e.g. using Apageo set etc.), dilatometric measuring in solid rock materials provide the possibility of more accurate reading of measured values and eliminate errors at the same time that arise due to the deformation of own membrane at pressiometric measuring in solid rock materials necessarily.

2.6. LOGGING MEASUREMENT

A broad set of logging methods was selected to fulfil requirements made on logging. State-of-the-art digital methods of wave acoustic logging and acoustic televisor have been used successfully in past years:

- *gamma logging* ***GR*** (natural radioactivity) - for basic division of lithology profile
- *neutron-neutron logging* ***XNN*** (determining the moisture content in rocks, free and chemically bonded in clay rock minerals - link with the degree of chemical weathering or tectonic deformation of rocks)
- *density logging* ***XGGDP*** (determining the specific volume weight and earmarking sections of deformed rock)
- *magnetic susceptibility logging* ***MS*** (earmarking rocks with a higher content of ferromagnetic materials and strongly altered rocks)
- *electric logging* ***EK (RAP010 and RAP041)*** in potential arrangement of 41 cm and 10 cm long wells - determining apparent electric resistance of rock masses - dividing rock masses according to lithology and degree of cracking
- *induction logging* ***IK (IK50 and IK80)*** 50 cm and 80 cm long wells - measuring conductivity of rock masses - dividing rock masses according to lithology and degree of cracking - the method may be applied also in dry borehole sections. This method replaces electric logging in dry boreholes,

- *acoustic logging* ***AK -*** determining the velocity of longitudinal waves propagation in rock masses and their attenuation using an analogue acoustic KAS-2-43 well and calculating derived parameters - strength in simple compression SIGS_K, deformation modulus ED_KAS, and shear modulus GD_KAS,
- *wave acoustic logging* ***AKFWS*** - the method facilitates recording full wave images and evaluating the velocity of longitudinal and transverse waves, which results in the calculation of Poisson’s ratio and of other geomechanical moduli (of deformation modulus ED_ALT and shear modulus GD_ALT among others) under favourable conditions,
- *acoustic televisor* ***ABI40*** - the method facilitates finding planes of discontinuity in the borehole profile (fissures resp. foliation planes mainly) and determining their spatial orientations (the gradient and azimuth),
- *cavern measuring****DIA*** - measuring the borehole diameter, finding open fissures and sections of unstable rock mass
- *hole deviation logging* ***IM***- measuring the spatial course of the borehole using deviation detector with a continuous recording of gradient and azimuth
- *resistance measuring* ***RMF00*** - measuring the specific electric resistance of water in the borehole
- *thermometry* ***TM*** - continuous measuring of water temperature in the borehole, serves to find out places of inflows or losses
- *photometry* ***FM***- measuring liquid clarity in the borehole
- *resistance measuring* ***RM***- determining the electric specific resistance of borehole fluid - conductivity

– *a set of resistance measuring methods for hydrogeology, namely:*

  resistance measuring based on filtration method (**RMF**) - measuring using method of marked liquid,

  resistance measuring based on method of constant pumping (**RM**) - or method of constant infusion (**RMN**).

2.7. MEASURING DYNAMIC EFFECTS IN THE BOREHOLE AT THE INSTITUTE OF PHYSICS OF THE CZECH ACADEMY OF SCIENCES

The purpose of measuring was defined for determining assumed dynamic effects to comply with requirements of the Institute of Physics of the Czech Academy of Sciences. Main directions were set for the required outputs before measuring:

- together with Ing. Jan Stěnička, Csc., base points for measuring the dynamic effects in the borehole of 60 m depth were set, at which a borehole of 10 m depth in the distance of 5 to 10 m as a source of vibrations was to be carried out (initially planned also in the 60 m depth, however, that is not simply feasible). The measuring in the borehole was carried out at six levels at once.
- finding the change of dynamic response with the change of distance from the vibrations source was the purpose of measuring.
- on 7. Nov. 2018, a meeting took place at the Institute of Physics of the Czech Academy of Sciences, where this proposal was discussed and it was agreed that measuring will be carried out in six of their localities at the same time. Four localities on the underground floors of buildings A and F were identified and locations for two indicators in higher floors of buildings A and F to be determined on the day of measuring. The methodology and evaluation of this measuring is included in a separate Annex No. 8 compiled by Inset s.r.o.

2.8. LABORATORY TESTS

Samples of soils, rock masses, groundwater, and petrographic samples were taken during drilling works. 168 pcs samples in total were taken for purpose of GT exploration. Samples analysed in laboratory provided data on geomechanical and geophysical properties of geological environment found.

The extent of samples taken is given in the previous chapter, in Table No. 2.

The extent of laboratory tests is given below, results of laboratory analyses are given in Annex of this report.

2.9. HYDROGEOLOGICAL WORK

In total 5 hydrogeologically equipped survey boreholes for both variants were carried out within the preliminary exploration. Indicative hydrodynamic tests were carried out in these boreholes (except HPJ12, HJ15, and HJ16 boreholes). Hydrodynamic tests were carried out and evaluated in compliance with ČSN EN ISO 22282-1 Geotechnical investigation and in compliance with ČSN 736614 Tests of groundwater sources. Field work were carried out in December 2018 to January 2019.

Wells HJ15 and HJ16 are used for the monitoring of groundwater table fluctuation only.

5 samples of groundwater in total were collected (5 to determine the aggressivity of water for building constructions according to ČSN EN 206 and 1 sample for the full chemical analysis) to verify the groundwater chemistry. Groundwater samples were collected in compliance with ČSN EN ISO 22475-1 and delivered to the laboratory within the shortest possible period of time. Samples were always collected in the dynamic condition. Values of electric conductivity, temperature, and pH of water were measured in the field directly at the same time with dynamic collection of groundwater samples.

Groundwater was found using EG survey boreholes, it was not possible, however, to collect groundwater beyond equipped hydrogeological boreholes due to using drilling technology with water flush. Samples of soils and rock masses were collected from the leach thus to determine the aggressiveness of groundwater for building constructions within exploration. 6 pcs soil/rock samples in total were collected for that purpose.

Within the exploration, archive certification of collecting objects was taken over that was supplemented by hydrogeological objects mapped newly in the vicinity of the construction.

The evaluation of affecting groundwater regimen in the surroundings of construction and inflows of groundwater to tunnels are summarized in the hydrogeological certificate of route below.

2.10. EVALUATION

The set of data obtained from drilling works, geophysical, hydrogeological, and pressiometric measuring and laboratory tests was used for constructing a longitudinal geotechnical section and compiling a table of geotechnical properties. Knowledge on conditions of tunnel excavating obtained by exploration is commented in next chapters.

3. GEOLOGICAL AND HYDROGEOLOGICAL CHARACTERISTIC OF TERRITORY

3.1. GEOMORPHOLOGY

We rank a territory of interest to following morphology sets according to regional zoning of relief:

System:	Hercynian
Province:	Bohemian Massif
Subprovince:	Berounka River Formations
Region:	Brdy Region
Set:	Prague Table Land
Subset:	Kladno Table Land
District	Hostivice Table Land

Vast areas of levelled surfaces of table land up to very slightly inclined relief are characteristic shapes of Prague Tableland relief, into which valleys of Vltava and tributaries cut deeply. Kladno Table Land covers the area of 556 km^2, has a mean height of 310.1 m a.s.l., and a mean gradient of 20-54°. A rugged upland with two levelled surfaces, the higher in altitudes 350-400 m s.l. and the lower 250-320 m s.l., arose on Proterozoic, less older Paleozoic, and Upper Cretaceous rock masses.

Vast areas of levelled surfaces (structural table lands) that incline very slightly from SW to NE (from 380-410 m to 340-350 m a.s.l.) are characteristic of Hostivice Table Land in the area of continuous extension of Upper Cretaceous rock masses. A wide alluvial depression reveals Cretaceous subgrade of Ordovician rock masses in the east, in the territory of urban development (between Veleslavín and Letná) The deeply cut steep-sided valley of medium and lower Šárecký brook (in Proterozoic shales and cobble stones) is of epigenetic origin.

The northern edge of the Střešovice Platform, being part of Prague Platform, makes up the area of interest. The original Central Bohemian peneplane that evolved after Cretaceous era was disintegrated by the erosion of left Vltava tributaries. The main phases of erosion fall up to the Pleistocene. They are dependent on gradual penetration of Vltava valley to the Prague basin. Veleslavín brook was the main erosion agent in the area of interest, the action of which carried away Upper Cretaceous sediments and uncovered subgrade rock masses of Ordovician age. Sliding movements made their mark at shaping slopes unloaded due to erosion in the Pleistocene climate. There were block slides in the territory concerned, when cracked blocks of Upper Cretaceous sandstones sunk to subgrade of scattered claystones and moved with them on the slope.

The human intervention manifested itself substantially in the morphology of the territory further. Sandstones were extracted in the mine in the south-eastern part of the territory, excavation in galleries cannot be excluded either, even though it is improbable in this territory populated from time immemorial. These galleries are filled with waste nowadays. At the spontaneous development of slopes in the territory, the ground was adapted to terraces - it was mined out in places, filled in places.

The human activity both historical and current is also important for terrain face. Veleslavínský brook drains the whole area to Vltava and the run-off coefficient depends on the terrain gradient mainly.

The altitude of terrain above sea level fluctuates within the range of altitudes 203-349 m a.s.l. It is the lowest at the construction beginning in the Stromovka area, the highest altitude is reached in the area of Military Hospital in Prague - Střešovice on the contrary and the terrain declines to 300-305 m a.s.l. elevation towards the end of construction.

The construction passes through a strongly urbanized territory.

3.2. GEOLOGICAL STRUCTURE OF THE AREA:

In regionally geological terms, the area of interest is part of Czech Massif that comprises rock masses of south-eastern wing of the Barrandian Lower Palaeozoic strata of Prague Basin and Mezozoic sedimentary rock masses of Czech Cretaceous Formation.

On the basis of new exploration works on the site of interest, the information from archive exploration works carried out in the area of interest, and further pursuant to engineering-geological map in 1:5,000 scale, sheets Prague 7-0, Prague 8-0 and Prague 8-1, the geological conditions can be characterised as complex in the area of interest.

The rock base in the area of interest is part of Barrandien Prague Basin and comprises Paleozoic rock masses of Ordovician. Dobrotivian series of strata is the oldest series of strata in the area of interest that evolved at the frontier of mid-Ordovician and Upper Ordovician. Libeň series of strata from Upper Ordovician is located in its overburden, on which the thickest Letná series of strata is seated.

A relict of Mezozoic Upper Cretaceous rock masses represented from the bottom by claystones to siltstones being part Peruc-Korycany series of strata of Cenoman overrides Ordovician rock masses in Střešovice area. The Cretaceous sequence continues further in the direction to the overburden by ferrugineous and kaolinite sandstones or even quartzy sandstones. These strata are overridden by a location of transition clay followed by a sequence of fine-grained sandy Cretaceous clays (sandy marl) of Turonian Bílá Hora series of strata.

Ordovician bedrock was affected by tectonic disturbances at Variscan folding due to the influence of pressures that acted and were released progressively inside the whole sedimentary basin. Tectonic disturbances are reflected in the form of several transverse fractures in the territory of interest, along which the rock masses are crushed considerably and their mechanical properties differ significantly from the surrounding unaffected material.

Capping masses are developed in the territory of interest, divided genetically to Eolian up Eolian-Diluvial, Diluvial, Diluviofluvial, and Fluvial sediments.

Dug up and relocated soils and rocks of the rocked, but also rubble, ash, and cinder were used for made-grounds.

Individual lithology types of soils and rock masses as they occur from the territory surface in the direction to the subgrade are set out briefly below.

3.2.1. Capping masses - quarternary sediment

The youngest capping masses are anthropogenic made-grounds. Made-grounds were found in form of asphalt road surfaces, loam-sandy or even sandy granular subbase and filling of excavations for underground services, and filling of original landscape unevennesses in the territory of interest. These backfillings are predominantly of the nature of sandy loam, gravel loam or even loamy sand with chips of bricks, shales and fine grain quartzy sandstones. The particle size distribution and lithology representation make anthropogenic deposits the most variable formation of the whole capping mass of territory of interest both horizontally and vertically. The thickness found varies from 0.1 to 2.5 m. The consistency is rigid to solid predominantly. Workability according to ČSN 73 3050 class3 - 4 (according to the content and size of gravel fraction) and class 5 at road construction. We classify made grounds into specific class Y according to ČSN P 73 1005.

Locations of Eolian and Eolian-Diluvial sediments (Pleistocene) of loess and loess-like loams nature of F4 to F6, less of F3 classes with small sandy marl chips are deposited under the layer of made-grounds in the eastern part of the tunnel route. It consists of low plasticity clay, brown-yellowish, with calcareous stringers, dark brown lamina sporadically for the most part, of solid consistency predominantly. Locations of buried soil horizons, having nature of clay with low plasticity, dark brown, with calcareous stringers in places, of F6/CL class, of rigid consistency are maintained in these sediments. These sediments reach the thickness up to 12.2 m in the area of eastern portal.

Two types of diluvial sediments were found on the route of future mined tunnel Střešovice in the course of exploration predominantly. In the first place, there are rough-grained sediments with clayish matrix at the toe of Cretaceous sandstones outcrops along streets Střešovická and Na Petřinách. These sediments have the nature of waste and mountain waste. They comprise blocks, boulders, and stones of Cretaceous rock masses. They have a structure of loamy or even clayish gravel predominantly, classes G4/GM and G5/GC. The second of deluvial sediments found is of nature of loam or even clay of medium plasticity and of sandy soil or even clay, classes F5/MI and F6/CI up to F3/MS and F4/CS predominantly, rigid consistency prevails

Relatively thick locations of diluviofluvial sediments are deposited in the area at the eastern portal of future mined tunnel under Eolian and Eolian-Diluvial sediments. Irregular alternations of clay-loamy and sandy locations are their characteristic feature. They are situated along the foot of slope from Dejvice to Ořechovka. These sediments thin out in the direction to the slope to Ořechovka gradually. The portal section will be carried out in Deluvio-Fluvial sediments mostly, where sandy clays and clayish sands with locations of clayish gravel, clay of medium plasticity and loams of medium plasticity prevail. Fine-grained soils are rigid or even solid mostly with a variable gravel content (rough-hewed chips of fine-grained quartz sandstones, sandy marls, and weathered shales up to size of 5 cm).

Fine-grained and rough-grained fluvial sediments of Dejvice terrace of the Vltava having nature of clayish fine-grained sands, sands with fine-grained admixture, and graded aggregate are deposited in the subgrade of deluvio-fluvial sediments. Strongly compacted rough waterlogged gravels form the base. The thickness fluctuates from 2.0 to 7.0 m. Workability according to ČSN 73 3050 class 3 - 4, class according to ČSN P 73 1005 class S5/SC, S3/S-F, F4/CS, G3/G-F, G2/GP.

The total thickness of quartenary sediments is around 36 m in the region of eastern portal.

The Quarternary nappe found was divided to following geotechnical types (geotypes) on the basis of description above:

An - anthropogenic made-grounds - recent, undifferentiated, considerably heterogeneous materials, class Y, workability according to ČSN 73 3050, class3 - 4 (according to the content and size of gravel fraction) and class 5 at road construction, according to ČSN 73 6133 class I.

Eol1 - Eolian and Eolian-Deluvial sediments - Pleistocene, loesses or even loess-like loams of sandy clay or even clay of medium plasticity nature, classes F4/CS up to F6/CI, solid consistency, workability according to ČSN 73 3050 class 3, according to ČSN 73 6133 class I.

Dl2+Dl3 - deluvial sediments - Pleistocene, loam or even clay of medium plasticity, loam or even sandy clay, clay gravel in few cases, classes F5/MI to F6/CI and F3/MS to F4/CS, G5/GC in few cases, of solid consistency mostly, workability according to ČSN 73 3050 class 3, according to ČSN 73 6133 class I.

Dl4 - deluvial sediments - Pleistocene, loamy or even clayish gravel, waste, classes

G4/GM to G5/GC, medium compacted, workability according to ČSN 73 3050 class 3, according to ČSN 73 6133 class I.

Dfl1+Dfl2 - deluviofluvial sediments - Pleistocene, sandy clay to clayish sand with locations of clayish gravel and locations of clay and loam mostly, classes F4/CS, S5/SC mostly, with G5/GC, F6/CL, F5/ML locations, of rigid or even solid consistency, workability according to ČSN 73 3050 class 2-3, according to ČSN 73 6133 class I.

Fl1+Fl2 - fluvial sediments - Dejvice terrace of Vltava - Pleistocene, clayish sand or even sand with an admixture of fine-grained soil, classes S5/SC to S3/S-F, compacted, workability according to ČSN 73 3050 class 3, according to ČSN 73 6133 class I.

Fl3 - fluvial sediments - Dejvice terrace of Vltava - Pleistocene, gravel with an admixture of fine-grained soil, poorly grained G3/G-F, G2/GP gravel, compacted, workability according to ČSN 73 3050 class 3-4, according to ČSN 73 6133 class I.

3.2.2. Pre-quarternary subbase

The highest preserved Cretaceous formations are sandy calciferous claystones (marlstones) - marl clays - of Bílá Hora strata in the area of interest. These are white-grey, yellowish to white-yellow, finely sandy marlstones, decalcified partly or fully from the top as a rule. Their rock-forming part are also quartz needles of spongia, so that some of their parts can be designated as spongilites. Some locations have the nature of marly limestones, others correspond rather to fine-grained marly sandstones. Bílá Hora sandy marls are preserved up to the thickness of 25 m. The weathering of sandy marlstones is relatively irregular. Sometimes it is decalcification only and rock masses have preserved strength, more solid parts alternate with locations of crumbly rock masses and chips of weathered sandy marls in places, however.

A complex of Upper Cretaceous sandstones, siltstones, and claystones follows in the subgrade of sandy marls. Glauconite grey-green sandstones (Korycany) of up to approx. 4.8 m thickness are situated in the topmost zone. They pass to Peruc sandstones of over 15 m thickness in the direction to the subgrade. Peruc sandstones have the nature of fine-grained to rough-grained rock masses with a characteristic light grey colour and irregular russet-brown stains. A continuous system of vertical fissures approx. perpendicular to each other penetrate both sandstone types that pass to open cracks at the table edge with an evident mutual displacement - having the nature both of subsidence and slight slewing of individual blocks. Claystones and siltstones build the subgrade of sandstones - zone Ia of Upper Cretaceous made by basal Cretaceous series of strata. These are freshwater sediments incurred by re-flooding old fossil weathered rocks of pre-Cretaceous relief. Claystones are of light grey or even dark grey colour, even black-grey, depending on the share of coal pigment and carbonized plants. Claystones contain a fine-grained sand admixture in places and turn to locations of clayish sandstones or even of young coal to humolite. Claystones represent a relatively impermeable environment, therefore shallow layer of water infiltrated from territory located higher stays on their surface. This water issues then in places of local depressions in the peripheral region of table land. Old sliding movements pulled out claystones on slopes including separated blocks of overburden sandstones in places frequently so that they got under the natural base of Cretaceous rock masses. Pulled out claystones are of nature of kneaded soil as a rule, of soft plastic soil with frequent sand admixture mostly. The existence - the presence of kneaded clays at the foot of sandstones indicates a risk of renewal of sliding movements in case of unsuitable interventions in the passive part of potential sliding surface. Claystones are bedded on shales of Ordovician subgrade in the basal part of Cretaceous sediments.

Cretaceous rock masses found were divided to following geotechnical types (geotypes) on the basis of description above:

KT - sandy marlstone (sandy marl) - Bílá Hora series of strata - Turonian - Upper Cretaceous Era - Mesozoic Era, yellow-grey, with russet-brown coatings on surface of discontinuities, stratified slab-like, class R3-R4, workability according to ČSN 73 3050 class 4, according to ČSN 73 6133 class II. These rock masses may occur rarely only in the variant centre, namely in the area at the Military Hospital Střešovice.

KCp - sandstone - Peruc-Korycany series of strata - Cenoman - Upper Cretaceous Era - Mesozoic Era, dark greenish white-grey, reddish light grey to russet-yellow, white-grey, fine-grained to medium-grained, glauconitic, quartz, kaolinic, class R6-R5, workability according to ČSN 73 3050 class 3-4, according to ČSN 73 6133 class I.

KCj - claystone or even siltstone - Peruc-Kyčany series of strata - Cenoman - Upper Cretaceous Era - Mesozoic Era, dark grey, with alternations of light grey silty insertions, with coaly pigment with transitions to coaly clay in places, of R5 class, workability according to ČSN 73 3050 class 4, according to ČSN 73 6133 class II.

3.2.3. Pre-Quarternary Nappe - Bottom Paleozoic – Ordovician period

The rock mass base of the territory of interest comprises Paleozoic rock masses of Letná series of strata - Ordovician in the eastern and southern part. Letná series of strata is the thickest formation of Barrandien Ordovician period locally (up to 650 m). It represents a significant formation that influences the morphology of Prague surroundings and of Prague itself substantially. It is part of Prague Barrandien Basin. They consist of greywacke and quartz sandstones, greywackes, siltstones, and shales that alternate fast in intervals of centimetres or even decimetres conditioned by seasonal changes. The material was depositing in shallow water of unsettled environment. Activities of waves and see streams carried and classified it. Trilobites prevail, brachiopoda, and echinoderma are prevalent in places of benthos fauna concentrated in the upper part of Letná series of strata above all.

Ordovician bedrock represented by Letná series of strata in the territory of interest was encountered in the development of silty shales and in the development of sand-clayish shales with sand patches in few cases. Shales are fine to rough micaceous and are stratified in slabs (6 - 20 cm). Abundant polishes were observed on strata areas. Fissures are open, filled frequently by allochtonous calcite or also clayish mass with shale splinters. Shale is deformed usually at contact with quartzites and crushed to splinters with clayish filling up to the distance of 3 cm. It changes colour to brown or even brown-russet due to weathering and decomposes to slabs, the layer surfaces of which are uneven. When they are decomposed fully, they slack to chips up to pieces of gravel nature with filling of sandy loam with sharp-edged chips of native rock. With diminishing intensity of weathering processes, the rock masses slack to pieces, lower to blocks with russet limonite (Fe oxides and hydroxides) coatings on planes of cleavage. Whirled lamination is apparent in the sandy-clayish development of rock mass that is indicated by alternations of lighter lamina richer in sand and darker lamina richer in clayish mass and dispersed coal mass.

Shales of Libeň series of strata were documented in the route in Ořechovka area. Libeň series of strata (Beroun stage) of thicknesses from 50 to 300 metres is divided to prevailing Libeň shales and less dominant Řevnice quartzites (I. Chlupáč, 1993). Řevnice quartzites are the hardest rocks of Prague rock subbase. They consist of slabs or even beds of light grey or even yellow-grey quartzites and quartz sandstones that are penetrated with small locations of shale in places. Dark clayish or even silty Libeň shales are deposited in the overburden of Řevnice quartzites that are heavily micaceous (Q. Záruba, 1948).

Dobrotivian series of strata (Dobrotivian stage) reaches the thickness from 100 to 400 metres and consists of Dobrotivian shales and less thick Skalka quartzites mostly. The series of strata is bordered by strong Řevnice resp. Skalka quartzites both in the overburden and in the subgrade that protect the series of strata against denudation. Micaceous Dobrotivian shales, clayish with silty admixture, dark grey or even black-grey, containing small spheroidal loam-sandy concretions and are penetrated by fissures densely that are tight mostly due to low hardness of shales (Q. Záruba, 1948). Rocks of this series of strata were found during exploration works in the area of western portal of mined tunnels where they sink into Cretaceous rock mass successively.

According to the petrographic analysis, silty shales or even clayish siltstones of Letná, Libeň, and Dobrotivian series of strata are grey-black, of solid and compact structure, without pronounced discontinuities (micro fissures). There are small threadlike micro fissures (of variable thickness and course) that are distinguishable microscopically only and healed by quartz almost solely, by carbonate exceptionally. A stratification is developed in most samples of shale that is distinguishable microscopically only. Contrary to other samples, a stratification is distinguishable macroscopically in one sample of Letná series of strata only. This stratification (lamination) is conditioned by alternations of locations (lamina, lenticels) arranged parallelly (subparallelly) with a higher content of psammite (aleuritic) fraction (sandstones, siltstones) and darker locations with a higher content of organic substances (silty shale—clayish siltstone). Individual rock types form lamina of various thicknesses (thinning-out lentils) or even thin slabs (layers) of thicknesses in millimetres or even centimetres. Mineral component parts are almost indistinguishable macroscopically. Small flakes of micas (muscovites) are apparent at stratified planes only (fracture surfaces in limitations of boring cores). Fracture surfaces are slightly uneven (wavy), weakly roughened (smoothed here and there). Discontinuous coats developed sporadically in limited rock mass samples (mostly areas of shale nature) that are formed by carbonate. The structure is aleuritic-pelitic to subovally psammitic. Mineral composition: quartz, feldspars (plagioclases), clayish mineral?, muscovite (sericite), chlorite; accessories: opaque ore mineral (pyrite), graphitic pigment-organic carbon, turmaline, zircon, apatite; secondary compositions (carbonate, Fe-Mn oxide-hydroxide).

More-or-less preferentially arranged phylosilicate texture (clayish mineral?, sericite, chlorite) form the prevailing part of silty shales or even clayish siltstones, in which aleuritic (psammitic) fraction (detritus) is represented. The phylosilicate texture (basic substance of the rock mass) is strongly diffusely dim (pigmented) by Fe-Mn oxide-hydroxides and soaked with pigment of organic carbon. Grains of quartz and sporadically represented feldspars (plagioclases) form the aleuritic (psammitic) fraction (detritus) of the granularity up to 0.15 mm. Grains are angular or even subangular, roughly isometric, weakly elongated here and there. Small grains of opaque ore mineral, zircons and apatites, represent subsidiary component of the detritus Isolated, preferentially oriented flakes of muscovites (sericites) and membranes of chlorites, size up to 0.2 mm, are dispersed sparsely and irregularly. Stratification is dependent on preferential arrangement of positions (lamina, lenticels) above all in case of all samples that petrographically correspond to small grain sandstones or even to siltstones. Small micro-fissures are apparent in the taken samples here and there that are healed mainly by quartz, sporadically by carbonate (limestone) or Fe-Mn oxides-hydroxides. The content of detritus (quartz grains markedly outweigh sporadically represented feldspars and accessorily represented heavy minerals - opaque ore mineral, zircon, apatite) fluctuates in the taken samplings depending on the rock mass texture. The content of detritus fluctuates between 10-30 %, in parts (positions) of rock mass formed by the prevailing phylosilicate texture (shale - siltstone), while the representation of detritus is approximately between 50-70 % in positions (lamina, lenticels) with higher content of psammitic (aleuritic) fraction (sandstones, marlstone). The average content of detritus fluctuates in the taken samples between approximately 30-60 % depending on the volume of positions (lamina, lenticels) with higher content of the psammitic fraction.

In the scope of Letná series of strata, positions (lenticels, membranes, lamina) with a higher content of sandy fraction (the petrography of these enclaves–parts of rock mass corresponds to fine grained sandstones) alternate with darker lamina (lenticels, membranes) with a higher content of oxides–Fe–Mn hydroxides, organic matters (graphitoid substances and opaque ore mineral) with a higher representation of shales (muskovites–sericites) and chlorites (the petrography of these enclaves–parts of rock mass corresponds to sandy shales). The fine-grained (0.05–0.18 mm) sandy fraction makes up the prevailing part (of enclaves).

Quartz grains are the převailing part of fine grained sandy (psammite) fraction that are represented by half-rounded to rounded, roughly isometric or more or less prolonged grains mostly. Small grains of opaque ore mineral of size to 0.1 mm (has the "fine powdery" character very often) are a common subsidiary to accessory component of rock mass (detritus). Small grains of tourmalines and zircons are a minor part of rock mass (detritus) . Irregularly dispersed, isolated, chaotically more-or-less preferentially arranged flakes of micas (muscovite) and chlorites of the size up to 0.5 mm are common subsidiary components of the rock mass. Small grains of tourmalines and zircons are represented exceptionally only. The bonding agent (matrix) is of porous character among grains and in intergranular spaces. It is composed of micro- to crypto-aggregate of phylosilicates "phylosilicate texture" (clayish mineral?, sericite, chlorite) together with small quartz grains for the most part. The bonding agent is soaked diffusely by oxides–Fe–Mn hydroxides and graphite pigment (organic carbon). A more-or-less preferentially arranged phylosilicate texture (clayish mineral?, sericite, chlorite) makes up the prevailing part of sandy shales (clayish sandstones) enclaves that is more-or-less soaked diffusely by oxides–Fe–Mn hydroxides and by pigment of organic graphite (graphite substances). Small grains of fine grained (0.05–0.18 mm) sandy fraction are subsidiary components of these enclaves. Quartz grains are the převailing part of fine grained sandy fraction that are represented by half-rounded to rounded, roughly isometric or more or less prolonged grains mostly. Irregularly dispersed, isolated, more-or-less preferentially arranged flakes of micas (sericites) and chlorites blanks of the size up to 0.5 mm are common parts of these enclaves.

The detritus content in samples taken vary depending on rock mass texture. Quartz grains outweigh feldspars represented sporadically and heavy minerals (opaque ore mineral, zirkon, apatite) represented as accessory component significantly in clasts (detrite). The content of detritus fluctuates between 10-30 %, in parts (enclaves) of rock mass formed by the prevailing phylosilicate texture (sandy shales), while the representation of detritus is approximately between 50-70 % in positions (lamina, lenticels) with higher content of psammitic (aleuritic) fraction (sandstones, marlstone). The average content of detritus fluctuates in the taken samples between approximately 30-60 % depending on the volume of positions (lamina, lenticels) with higher content of the psammitic fraction.

Furthermore, thicker parts and interpositions (of 0.5-approximately 5 meters thickness) of fine grained greywacke sandstone with carbonate binder (regular alternation) in the scope of Letná series of strata were delimited in the petrographic description in the scope of silty shales sequence. The average **quartz content** is in the range of **85-90%.** The rock mass undergone a significant silicification leading to an irregular growing up of quartz grains (emergence of regenerative structure).

The rock mass is of light grey colour, of massive and compact structure, without notable discontinuities (micro-fissures). Discontinuities (micro-fissures) have a variable thickness and course are healed by carbonate almost solely. Mineral component parts are almost indistinguishable macroscopically. Small flakes of micas (muscovites) are only apparent at the strata planes. Fracture surfaces are slightly uneven (wavy), weakly roughened. The structure is subangularly to subovally psammitic with porous binder (omnidirectionally grainy binder). Mineral composition: carbonate (limestone), quartz, feldspars (plagioclases), opaque ore mineral; accessories: muscovite (sericite), chlorite, biotite, tourmaline, glauconite, zircon, apatite, bioclastics; secondary components (organic pigment - organic carbon, Fe oxide-hydroxide). Prevailing part of the rock mass is formed by psammitic fraction of granularity 0.05-0.25 mm that is deposited in a carbonate binder. The carbonate binder is formed by fine grain aggregate of small crystals (omnidirectionally grainy binder - fine grain sparry calcite) that are more-or-less pigmented by Fe oxides-hydroxides here and there. Exceptional component of the carbonate binder are small organic remains-fossils (bioclastics), mainly small shells, or fragments of forams (Foraminifera) and molluscs of various sizes. Grains of quartz are the main part of fine grain psammitic fraction as well as grains of feldspars (plagioclases) represented to smaller extent. Quartz is mostly represented by half-rounded or even half-sharp grains, sporadically by perfectly rounded, roughly isometric or more-or-less elongated grains. Grains are mostly monocrystalline with undulose extinction without more notable blistering. Feldspars, represented to smaller extent, are represented by practically sound grains go plagioclases. Homogeneous grains are represented in the rock mass; we observe polysynthetic lamination of plagioclases to smaller extent. Subsidiary components of the rock mass are irregularly dispersed, isolated, with mostly more-or-less preferentially arranged flakes of micas (muscovite, biotite) and sporadically chlorites of the size up to 0.25 mm. Small grains of opaque ore mineral of the size up to 0.2 mm are a common accessory component that is represented in form of irregular grains. Small grains of glauconites, tourmalines, zircons and apatites are represented exceptionally only.

The Ordovician rock masses can be divided based on individual weathering degrees into following geotechnical types:

LETNÁ SERIES OF STRATA - ORDOVICIAN

Ltn/W5-W4 - silty shale, fully weathered (decomposed) or even heavily weathered, W5-W4, of sandy loam or even sandy clay nature, dark grey, with russet streaks, chips or even splinters of slightly micaceous shale or even black-grey shale nature, with russet streaks, slightly micaceous, slacking to pieces or even chips, **class R6-R5**, workability according to ČSN 73 3050 class 3, according to ČSN 73 6133 class I

Ltn/W3 - silty shale, slightly weathered, W3, black-grey, with russet coatings on surfaces of discontinuities, slightly micaceous, slacking to pieces or even chips, **class R5**, workability according to ČSN 73 3050 class 3, according to ČSN 73 6133 class I

Ltn/W2 - silty shale, weakly weathered, W2, black-grey, with russet coatings on surfaces of discontinuities in places, slightly micaceous, stratified in slabs, **class R4**, workability according to ČSN 73 3050 class 4, according to ČSN 73 6133 class II

Ltn/W1 - silty shale, sound, W1, dark grey, **class R4-R3** with light sandy patches or even lamina of fine-grained quartz sandstone or even fine-grained sandstone with carbonate binder, **class R2**, workability according to ČSN 73 3050, class 5, according to ČSN 73 6133 class II

Ltn/TEKT - silty shale, heavily tectonically disrupted, of sandy loam or even sandy clay nature, black-grey, with chips or even splinters of slightly micaceous shale, whirled up structure, **class R5** or even **R6-R5**, workability according to ČSN 73 3050, class 3, according to ČSN 73 6133 class I

LIBEŇ SERIES OF STRATA – ORDOVICIAN – will not be encountered in the scope of

<u>variant centre</u>

Lbn/W5-W4 - silty shale, fully weathered (decomposed) or even heavily weathered, W5-W4, nature of CI/F6 clay with medium or even low plasticity, russet-brown, with grey streaks, of rigid consistency or even the nature of shale slacking to small chips or even splinters, **class R6-R5**, workability according to ČSN 73 3050 class 3, according to ČSN 73 6133 class I

Lbn/W3 - silty shale, slightly weathered, W3, black-grey with russet coatings on chips, slacking to chips or even pieces, rolling, smooth stratum surfaces **class R5**, workability according to ČSN 73 3050 class 3, according to ČSN 73 6133 class I

Lbn/W2 - silty shale, weakly weathered, W2, black-grey, with russet coatings on surfaces of discontinuities, stratified to slabs or even thin slabs, strongly micaceous, **class R4**, workability according to ČSN 73 3050 class 4, according to ČSN 73 6133 class II

Lbn/W1 - silty shale, sound, W1, black-grey, stratified to slabs or even thin slabs, strongly micaceous, **class R4-R3**, workability according to ČSN 73 3050 class 5, according to ČSN 73 6133 class II

<u>DOBROTIVIAN SERIES OF STRATA - ORDOVICIAN</u>

Dbr/W5-W4 - silty or even clay-silty shale, fully weathered (decomposed) or even heavily weathered, W5-W4, nature of CI/F6 clay with medium or even low plasticity, black-grey, with russet-brown streaks, of rigid consistency or even the nature of shale slacking to small chips or even splinters, **class R6**, workability according to ČSN 73 3050 class 3, according to ČSN 73 6133 class I

Dbr/W3 - silty or even clay-silty shale, slightly weathered, W3, black-grey with russet coatings on chips, slacking to chips or even pieces, rolling, smooth stratum surfaces, **class R5**, workability according to ČSN 73 3050 class 3, according to ČSN 73 6133 class I

Dbr/W2 - silty or even clay-silty shale, weakly weathered, W2, black-grey, with russet coatings on surfaces of discontinuities, slacking to thin slabs, **class R4**, workability according to ČSN 73 3050 class 4, according to ČSN 73 6133 class II

Dbr/W1 - silty or even clay-silty shale, sound, W1, black-grey, slacking to slabs or even thin slabs, **class R4-R3**, workability according to ČSN 73 3050 class 5, according to ČSN 73 6133 class II

Dbr/TEKT - silty or even clay-silty shale, heavily tectonically disrupted, black-grey, crushed to chips or even splinters, polishes evident on surfaces of discontinuities, healed by limestone stringers, slacking to pieces, whirled up structure, **class R6**, workability according to ČSN 73 3050 class 3, according to ČSN 73 6133 class I

3.3. <u>ZONES OF WEATHERING OF PRE-QUARTERNARY BASE</u>

Following zones of weathering of subgrade rock masses were differentiated within the meaning of ČSN 72 1001 that is not valid now. The current ČSN EN ISO 14689-1 standard maintains the principle of breakdown, however, with a different alphanumeric marking. Following breakdown of rock masses was applied to maintain the continuity with previous exploration stages:

decomposed	W5 - >75% weathered minerals	falls to geotype
heavily weathered	W4 - 35 - 75% weathered minerals	falls to geotype
slightly weathered	W3 - 10 - 35% weathered minerals	falls to geotype
weakly weathered	W2 - 3 - 10% weathered minerals	falls to geotype
sound	W1 - 0 - 3% weathered minerals	falls to geotype

Table No. 3.3.1. - Categorisation of rock masses according to strength

ČSN P 73 1005		**Strength**	**ČSN EN ISO 14689-1**	
class	**strength**	**σ_c (MPa)**	**name**	**class**
R1	very high	> 250	extremely solid	RS0
		250 – 150	very solid	RS1
R2	high	150 – 100		
		100 – 50	solid	RS2
R3	medium	50 – 25	medium solid	RS3
		25 – 15	soft	RS4
R4	low	15 – 5		
R5	very low	5 – 1.5	very soft	RS5
R6	extremely low	1.5 – 1.0		
		1.0 – 0.5	extremely low	RS6
		< 0.5		

Legend: RS (rock strength) – the author introduced marking of his own given the absence of designations of classes

We present tables for the sake of lucidity in the following text that contain evaluation of rock massif according to weathering degrees and according to distance of discontinuities in terms of the standard ČSN EN ISO 14689-1 – Geotechnical investigation and testing – Designation and Categorization of Rock Masses – Part 1: Designation and description (ČSN 72 1005) of 10/2004.

Table No. 3.3.2. – Distance of discontinuities according to ČSN EN ISO 14689-1

Name	**Distance (mm)**	**Degree**
very high	> 2 000	1
major	2.000 – 600	2
medium	600 – 200	3
low	200 – 60	4
very low	60 – 20	5
extremely low	< 20	6

3.4. HYDROGEOLOGICAL AND HYDROLOGICAL CONDITIONS

The territory of interest belongs to hydrogeological district ID 6250, proterozoic and palezoic in the river basin of Vltava tributaries (groundwater formation of the basic layer ID

62500 proterozoic and Paleozoic in the river basin of Vltava tributaries) that is generally characterized by free water table, total mineralization 0.3-1g /l, low transmissivity (<1.10^{-4} m^2/s), chemical type Ca-Mg-HCO_3-SO_4.

Three basic collectors can be distinguished in the wider vicinity of the territory of interest from the hydrogeological viewpoint. Non-lihificated quarternary sediments represent the first one, in which intrinsic permeability may only be expected. Cretaceous sedimentary rock masses are the second one where fissure permeability can be expected in claystones and marlstones, while combined intrinsic-fissure permeability in sandstones. Semi-rocky Palaeozoic (Ordovician) rock masses with fissure permeability are the third collector.

The presented breakdown is schematic only; hydrogeological conditions are often more complicated, as groundwater of particular horizons communicate mutually.

Lower Paleozoic - Ordovician - fissure water regimen occurs in rock masses; the rock masses are for water practically non-permeable in unweathered condition. Groundwater horizon originates only in a zone of surface fissure disjoining in weakly weathered rock masses near the surface of the rocky subbase. Rock masses contain dense mesh of small fissures here, in which groundwater circulates and almost continuous groundwater table is formed depending on their filling. The thickness of watterlogged horizon is influenced by number of factors in Ordovician rock masses, especially by weathering degree, by thickness of nappes as well as by morphology of the territory. Water penetrates to greater depths in fissured steeply deposited quartzites and in disturbance zones only.

In the area of interest, strata of various lithological development and thus also various hydrogeological properties are found. Soft, clayish shales (Libeň, Dobrotivian strata) are relatively least permeable. Shales with greater silty and sandy admixture (Šárka strata) have the hydrogeological properties only slightly more favourable. Local and indistinctive groundwater horizons originate in shales with insertions of siliceous sandstones and quartzites (Letná strata). Skalka strata, represented by quartzites predominantly, have specific hydrogeological properties. They either make possible penetration of groundwater in fissured positions to great depth, or contrariwise, have the effect of a dam of groundwater horizon.

Groundwater can circulate only along open fissures without clay filling or in tectonically crushed zones. The yield of these horizons is generally low. Permeability increases with growing fine grain and chippy component in weathered and fissured parts of rock masses. It concerns combined fissure-intrinsic regimen in this case.

Groundwater flows generally in the north-north-east to north-east direction towards the Vltava river course that makes regional drainage base of the territory.

Permeability fluctuates in Ordovician rock masses approximately in the order range kf = 10^{-5} m/s (sandy shales with quartzite insertions) to 109 m/s (clayish shales of unweathered condition) according to archive documents (Kameníček, I. et al., 1971, Kunovjánek, A., Říha, V., 2010). Archive data documents (Kameníček, I. et al., 1971) specify the yield of groundwater inflows to individual HG boreholes in Ordovician rock masses from 0.008 to 0.08 l/s, greater yields were reached at places only where groundwater seepage occurs from the close, higher situated waterlogged capping formations (chalk, Pleistocene terraces).

Upper chalk - it concerns combined intrinsic-fissure water regimen in rock masses of sandstone nature. Groundwater forms continuous groundwater collector at the base of Korycany sandstones (cenoman) in overburden of Peruc claystones (cenoman) of limited permeability. This collector is received by water galleries of the Castle Water Duct. Peruc claystones form a practically impermeable insulator separating the Cretaceous water content from the water content of Ordovician rock masses. The function of insulator is considerably limited in case of low thicknesses of Peruc claystones and their eventual blistering and mutual communication of both collector occur.

The groundwater table is sank almost to the base of Korycany sandstones (cenoman) in the Cretaceous collector; the thickness of water content is in order of units of meters here according to archive documents. Groundwater flows out on weakly permeable Peruc claystones towards N and NE where it is drained on outcrops of Cretaceous rock masses to quarternary diluvial deposits. Dotation of the deeper groundwater occurs in Ordovician shales to limited extent only. The permeability of intrinsic-fissure collector of cenoman sandstones is approximately in order of k_f = 10^{-5} m/s according to archive documents (Kunovjánek, AND., Říha, V., 2010).

It concerns fissure water regimen in overburden sandy marls and marlstones of Bílá Hora series of strata; rock mass are for water practically impermeable.in unweathered condition Groundwater can circulate only along open fissures without clay filling or in tectonically crushed zones. The yield of these horizons is generally low. Permeability of such fissure collector will vary in the range in order of k_f = 10^{-6} to 10^{-8} m/s.

Table No. 3.4.a - Results of chemical laboratory analyses of groundwater

Borehole	Elevation of borehole mouth (m a.s.l.)	Date of measuring settled level	Depth of the water table (m)		Elevation of table (m a.s.l.)	
			reached	settled	reached	settled
HJ1	240.709	15 Dec. 2018	24.80 and 33.20	33.61	215.91	207.10
PJ2	240.703	-	27.50 and 33.70	cannot be measured	213.20	-
HPJ4	270.948	15 Dec. 2018	6.0	4.35	264.95	266.60
J4a	270.770	7 Dec. 2018	6.0	4.35	264.77	266.42
J3	268.740	10 Jan. 2019	7.0	6.5	261.74	262.24
J5	276.100	-	7.0	not determined	269.10	-
J6	294.060	-	12.0	not determined	282.06	-
PJ7	335.280	-	it was not possible to establish with regard to the drilling technology used			
HJ8	305.650	15 Jan. 2019	3.50	6.15	237.21	299.50
PJ9	302.452	-	8.50	cannot be measured	293.95	-
J10	310.135	16 Jan. 2019	-	14.32	-	295.82
J11	349.413	-	it was not possible to establish with regard to the drilling technology used			
HPJ12	240.97	20 June 2019	27.00	31.70	213.97	209.27
PJ13	241.66	-	31.00	not determined	210.66	-
J14	276.15	-	9.50	10.60	266.65	265.55
HJ15	301.50	28 Apr. 2020	8.20	5.23	293.10	296.27
HJ16	346.50	-	29.00	30.12	317.50	316.38

The tunnel is designed as unilaterally inclined towards the beginning of the construction, i.e. towards the Vltava river (towards Stromovka park).

The territory of interest belongs to the Labe river basin, it is a component of the hydrogeological catch basin of 2nd order, No. 1-12 – Vltava from Berounka to the estuary and Labe from Vltava to Ohře further.

Major part of the construction belongs to the **catch basin of Vltava water course**, No. of hydrological sequence 1-12-02-0010-0-00 with total area of 27 146.68 km^2.

Short section of the construction within the range of chainage at approximately km 6.0-6.6 belongs to **Brusnice catch basin,** No. of hydrological sequence 1-12-01-0240-0-00 with total area of 4.72 km^2.

The territory of interest is not situated in protection zone of other water source in terms of the Decree No. 137/1999 Coll. Territory destined for course of the future railway line does not belong to territory of protected area of natural accumulation of groundwater – CHOPAV, or of spa or balneological water.

3.4.1. Influencing the groundwater regimen in the surroundings of the project

The course of the designed route leads through the urban area of the City of Prague where buildings are supplied by water mains. Wells are used only as sources of service water and for watering gardens in most cases. Unused sources of groundwater are also included in the evidence; they serve the purpose of information about unaffected water table condition.

The archive condition survey of abstraction structures was taken over within the survey, (wells mapped within detailed hydrogeological maps of Prague in the scale of 1: 5,000). It was completed with newly mapped hydrogeological structures in close vicinity of the construction (e.g. shallow unused wells at the premises of the Institute of Geophysics). These are excavated wells in most cases using a collector with shallow groundwater circulation.

Locations of individual documented hydrogeological structures are mapped in detail at the situation layout in the Annex No. 1.

New deep bored wells and deep boreholes with collectors of heat pumps were executed in the assessed territory in latest years. These boreholes are often not documented in archives of ČGS (Czech Geological Survey).

The well S-11 (map sheet Prague 8-0) was ascertained in the previous route variant that was situated in the route mined tunnel and was not passportized for reasons of not-catching the owner. Its depth is not specified in archive documents, but we expect, that it does not exceed 10 m with respect to the nearby abstraction structures (wells at the premises of the Institute of Geophysics) and the hydrogeological conditions. If the route is changed back to the original horizontal alignment again, we recommend to carry out monitoring at the specified well.

Furthermore, deep boreholes for heat pumps were ascertained in the archive of ČGS (Czech Geological Survey) - Geofond for the previous variant, namely at the plot No. 730, Slavíčkova Street Prague 6 - Bubeneč (out of the designed route). In this case, notifications on the survey execution only exist for the respective boreholes according to information from Water Right Authority and Building Control Department of the City District Prague 6; no further documents are registered for eventual boreholes or wells (permits, approvals, etc.) at the respective authorities.

Significant abstraction structure – the Castle Water Duct – passes in the vicinity of the designed construction. It collects shallow groundwater from the area of the Liboc Pond as well as groundwater of Cretaceous deposits of the Střešovice plane (by means of several galleries of expected length of 20 - 130 m) according to archive documents (information from the Water Right Authority of the Office of City District Prague 6, taken over from - Soukup, J., Koroš, I. (2016)). The Castle Water Duct collects groundwater of first tens l/s yield overall. The Castle Water Duct is used as a source of service water. The location of Castle Water Duct and of infiltration galleries is shown in the detailed layout. The Cretaceous collector will not be adversely influenced by the designed construction of the mined tunnel, it is necessary to ensure technical execution (unsealing) only in case of individual building structures (e.g. exhausts) leading to the surface in the area of Cretaceous plane so that the Cretaceous collector is not permanently drained towards depth.

No deeper bored wells or boreholes for heat pumps are situated at premises of the Střešovice Military Hospital according to the archive documents taken over (HG literature search by GeoTec-GS, a.s., 2016).

No excavated wells are situated at the premises of heating plant in Veleslavín according to information of the site administrator; groundwater collected by the gallery for hot water pipeline (ballast water) is used as service water here – the gallery receives groundwater collector bonded to Cretaceous sandstones that will not be influenced by the designed construction. The excavated well S14/P007707 mentioned in archive documents (Papoušek, L., 1959) is not situated here any more here presently.

3.4.2. Aggressiveness of the rock environment

Groundwater was found using EG survey boreholes, it was not possible, however, to collect groundwater beyond equipped hydrogeological boreholes due to using drilling technology with water flush. Samples of soils and rock masses were collected from the leach thus to determine the aggressiveness of groundwater for building constructions within exploration. Protocols of laboratory analyses of water from survey boreholes are presented in Annex No. 5 of this report, including water samples taken within hydrodynamic tests of boreholes that are also presented with appropriate commentary in Annex No. 6.

Summary of individual parameter values ascertained by laboratory analyses is presented in attached tables.

The aggressively XA1 (weak) was ascertained in the executed analyses at maximum

No parameter of the weak aggressiveness degree XA1 was exceeded in any of the taken samples. Certain terminological vacuum arises in these cases, since the respective standard ČSN EN 206 does not contain the term for non-aggressive groundwater. The degree of aggressiveness XA1 could be considered in the entire construction extent. Since it was not possible to perform representative set of analyses presently in the area of the mined Střešovice tunnels (where the tunnelling will be carried out in Ordovician rock masses predominantly) and, above all with regard to archive analyses for other underground constructions in rock masses of Prague Ordovician, the aggressivity degree up to XA2 can be recommended for tunnelling in Ordovician rock masses.

3.5. RISKS OF GEOLOGICAL ORIGIN

3.5.1. Slope movements

The construction of Střešovice mined tunnels, variant centre, should not influence the activation of registered slope movements (slides, rock falls and the like). The registration of slope movements is kept long-term by the Czech Geological Survey - Geofond. No slides are presently registered in the wider vicinity of the designed construction at the web sides www.geology.cz - geological map server (status on 10/6/2020). The potential landslide registered in the archive of ČGS (Czech Geological Survey) under number 784 Prague-Střešovice Slope Sliding under Andělka in Střešovice is the nearest geodynamic phenomenon. It was documented in the year 1963.

The numbers 1979 (stabilized roll documented in the year 1972) and 1980 (buried block shift in Břevnov cadastre documented in the year 1978) are the only landslides registered by the archive of ČGS (Czech Geological Survey) in the wider vicinity.

At EG map 1: 5000, block movements are also marked at the northern boundary of the Cretaceous table relict in the area of Střešovice Rocks It concerns mainly sandstone rock mass blocks desintegrated by frost and boulders that moved on underbed cretaceous claystones of Peruc strata. Block movements are assessed as seated. The Czech Geological Service - Geofond Prague does not register the territory concerned as a territory affected by geodynamic manifestations at present. If the variant - Centre is pursued further, we recommend to carry out a site survey in the next project stage to verify the up-to-date manifestations of geodynamic processes. It can be judged relevantly on the basis of the results of the survey, if the future structure may adversely affect the stability of Střešovice Rocks area. It is necessary to minimise possible manifestations of tunnel mining on the terrain surface (subsidences) in the given section of construction.

Fig. No. 1: Recorded slides:

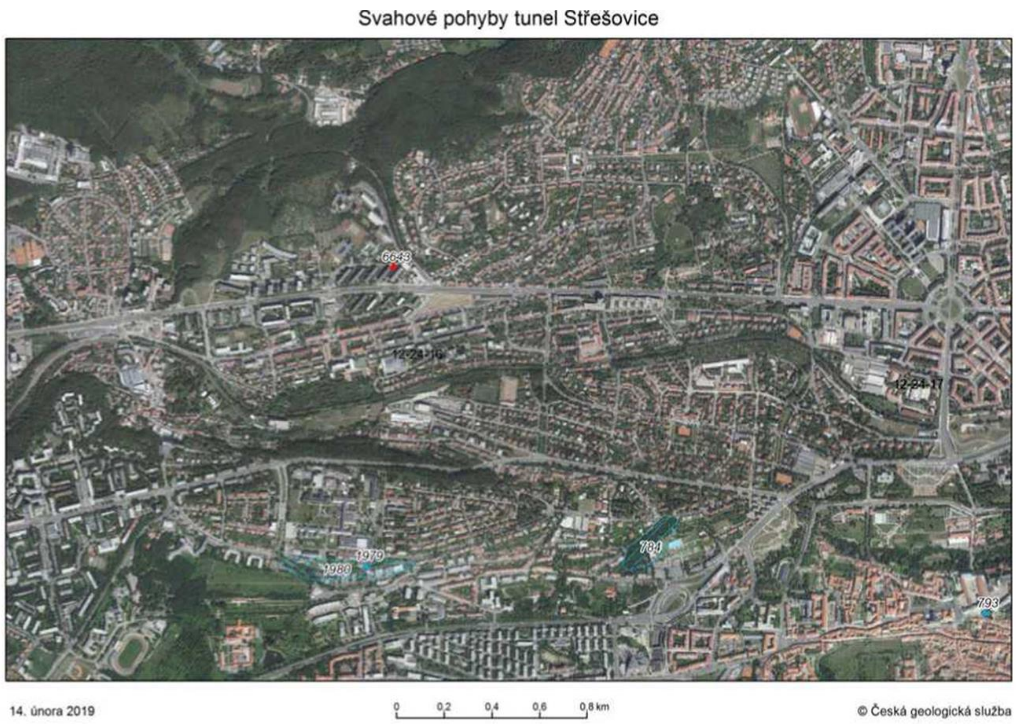
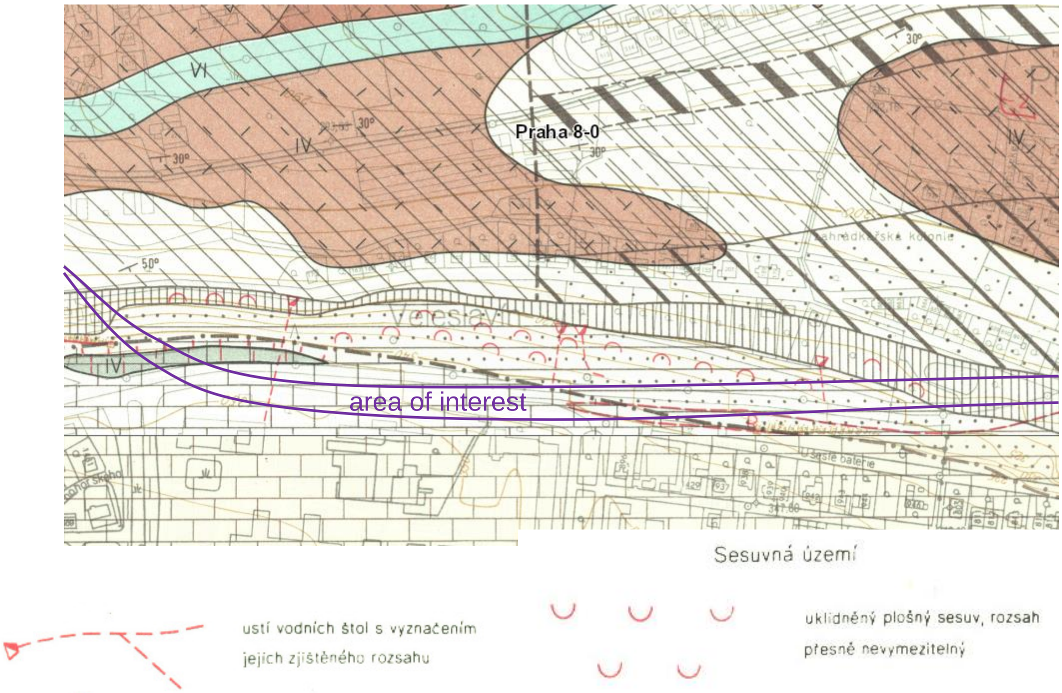


Fig. No. 2: Seated slides in the area of Střešovice Rocks (Basic EG map 1:5000, sheet Prague 8-0, Králová Z. 1971, PUDIS Praha)



3.5.2. Undercutting

The locality does not belong to a territory endangered owing to undercutting, but old galleries are situated in the locality of interest. These are the collecting galleries of so called Castle Water Duct that was built in 16th century. They are all are founded on the northern slope of Střešovice plane on the base of Cretaceous aquifer in cenoman sandstone or on contact with basal claystones that form an insulator. There are collecting galleries II, III, IV, V, and VI in the wider vicinity of the mined Střešovice tunnels Galleries III, IV, and VI – see Fig. No. 2. occur in the immediate overburden of mined tunnels (however, without collision as far as height is concerned) Gallery No. V does not intervene in the tunnel area according to geodetic measurements carried out – see similar layout. It is necessary to minimise possible manifestations of tunnel excavation on the terrain surface (subsidences) in the area of galleries.

Fig. No. 3: Diagram of the Castle (Royal) Water Duct

3.5.3. Heat pumps and wells in the route or vicinity of the tunnel

No direct collision will occur due to the above specified construction with deep bored wells or with boreholes for heat pumps from the viewpoint of designed route of the mined tunnel according to available archive documents of ČGS (Czech Geological Survey) - Geofond

Prague. However, presence of deep wells and heat pumps, the documentation of which is not registered in the Geofond, is not ruled out in the route mined tunnels. It will be necessary to verify this assumption in further phase of the project preparation after the route of the tunnels is stabilized.

3.6. SEISMIC ACTIVITY

The territory of interest belongs among areas with very small seismicity according to ČSN EN 1998-1 (73 0036), the values subsoil reference acceleration a_{gR} do not exceed 0.02 g in the respective area. According to the standard ČSN EN 1998-1:2004, we recommend to proceed in the respective locality **according to the table 3.3** (magnitude-surface waves M_s can be expected higher than 5.5°) with values of parameters describing the spectrum of elastic**response of the type 2**. The locality belongs to the subsoil type**A** – (rocky stone massif or geological formation of rocky stone mass type with overburden of softer material of maximum thickness up to 5 m) and **C** – (thick sediments of medium compact or compact sand, gravel or rigid clay in thickness from several tenths to hundredths meters).

We recommend to consider the subsoil reference acceleration of $_{gR}$ do 0.02g based on the map of seismic areas.

(note: such areas are considered in the Czech Republic to be cases of very small seismicity with no necessity to observe provisions of ČSN EN 1998-1 where the value a_{gR}, used for calculation of seismic load is not greater than 0.05g) according to NA 2.8. Clause 3.2.1. of above mentioned standard.

3.7. WATERLOGGING

More extensive areas of waterlogging were not documented in the territory of interest. Waterlogging of levelled area was only noticed in premises of the old heating plant in Veleslavín near the slope toe, to the north from the crossing of Nad Hradním Potokem and Na Hradním Vodovodu Streets according to oral information of the heating plant staff members. Even a continuous water table formed here on the ground surface in period with high precipitations. These are probably places of groundwater overflowing from Cretaceous sediments to diluvial sediments and its springing to surface.

3.8. FURTHER INFLUENCES OF GEOLOGICAL ORIGIN

An occurrence of mine gases (CH_4, CO, CO_2) cannot be expected in the rock mass environment at tunnelling the galleries. Furthermore, no rock masses affected by karst phenomena occur in the route of Radlice collector and it is not a territory with risk of groundwater rushes to the underground construction (extraordinary inflows of groundwater may occur in environment of Ltn/TEKT and Dbr/TEKT geotypes only).

3.9. SPECIALLY PROTECTED AREAS

The construction passes the western edge under the Natural Monument Střešovice Rocks (the length of the collision section makes up 140 m approximately). Reason of protection: Sandstone rocks with natural caves and fissures significant from viewpoint of geology as well as landscape.

Substantial part of the territory is formed by rocky defile consisting of bottom turon sandstones with typical radial tectonics. It is possible to see interesting elements of sandstone decomposition with natural as well as modified small caves here. The sandstones are more eroded by weathering (seepage of precipitation water from above) in the upper part, they are only little lihificated and their decomposition to sand as well as boulders occurs. The territory represents a boundary part of the Cretaceous table rising above the Prague basin geomorphologically.

Fig. No. 3: Natural monument Střešovice Rocks

3.10. CLIMATIC CHARACTERISTIC

The climatic characteristic was elaborated based on monthly amounts of the station Prague - Ruzyně. Precipitation amounts of the 12 months preceding the survey and their comparison with long-term normals for the 1961 – 1990 period are specified in the table 4.5.1.

Table 3.10.a: Precipitations at the station Prague - Ruzyně, amounts v mm and their comparison with long-term averages

period	Months of the year 2018												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	year
2019	13.2	11.5	26.9	23.8	71	36.8	34.1	85.5	38.4	27.3	29.9	9.1	407.5
1961-1990	21.6	21.4	26.3	34.9	67.2	63.5	58.7	67.5	33.0	26.5	29.9	22.3	472.8
% of normal	61.11	53.73	102.28	68.19	105.65	57.95	58.09	126.66	116.36	103.01	100.00	40.80	86.18

The year 2019 was a period below the average as regards precipitation, with the highest precipitation deficit in the month of December, further in February, June, and July. The months March, June, September and December were above average periods as regards precipitation compared to the long-term precipitation normal. The year 2019 was below the average from the viewpoint of precipitation amount, namely by approximately 14% of expected precipitations.

The territory of interest is situated in the B2 region from the viewpoint of climatic classification according to the Climate Atlas of Czechia (2007) (moderately warm, moderately dry, with moderate winters predominantly).

Climatic data are taken over from the Climate Atlas of Czechia (2007):

Average yearly air temperature	9 – 10 °C
Average number of frost days a year	80 – 100
Average yearly number of ice days	up to 30
Average yearly number of days without frost	260 – 300
Average yearly number of summer days	40 – 50
Average number of days with snow cover	30 – 40
Average maximum of snow cover up to	15 cm
Average date of the first snowing	10 Nov. – 20 Nov.
Average date of the last snowing	10 4. – 20 4.
Average amount of precipitations	500 – 550 mm

4. LABORATORY AND FIELD GEOTECHNICAL TESTS

4.1. TASK AND SCOPE OF TESTS

4.1.1. Laboratory tests

Laboratory tests focused on ascertaining **basic physical** (granularity, consistency limits, specific gravity, natural humidity), **mechanical** (shear strength and compressibility soils, compressive strength rock mass) as well as **technological** (abrasiveness) **properties of** soils of capping masses as well as rock masses of rockbed. Furthermore, water samples were also taken from boreholes for simplified analysis for construction purposes. The following was taken in total for examination of these properties:

- **disrupted soil samples..........26**
- **technological soil samples.......... 6**
- **non-disrupted soil samples..........15**
- **rock mass samples..........85**
- **samples of soil aggressiveness.......... 8**
- **water samples 2**

In case of these taken samples, laboratory tests and analyses were conducted as follows:

- **set of index tests of soils..........48**
- **direct shear test.......... 9**
- **compressibility in oedometer including coefficient of consolidation and determination of swelling pressure 2**
- **swelling pressure of soils.......... 1**
- **sinkability of soils.......... 2**
- **simple compression strength of rock masses 45**
- **strength index of rock masses..........45**
- **abrasiveness of rock masses..........12**
- **petrographic analysis of rock masses..........11**
- **complete chemical analysis of groundwater (aggressivity to concrete).......... 2**
- **abrasiveness of soils 8**

- **content of CaCO3 .... 2**

4.1.2. Field tests

Out of field tests , in total **34 pressiometric tests** were carried out in total 5 boreholes, the results of which were used for describing the strength and deformation properties of basic types soils/rock masses at the route after comparison with geological composition in other newly executed as well as further archive boreholes. Protocols of individual tests and analyses are attached collectively in Annex No. 9 of the report.

4.2. METHODS USED

■ **Natural humidity w** (%) is determined by the procedure according to ČSN CEN ISO/TS 17892-1.

■ **Specific gravity - density** γ_n (kg.m^{-3}) - is determined from taken samples according to ČSN CEN ISO/TS 17892-2.

■ **Consistency limits - liquid limit WL** (%), **plasticity limit WP** (%) **and plasticity number IP** (%) are determined according to ČSN CEN ISO/TS 17892-12.

■ **Granularity composition of soils** is determined by combination of grain size analysis and densimetric method (according to Cassagrande), in accordance with ČSN CEN ISO/TS 17892-4. The name symbol of soils is subsequently determined according to ČSN EN ISO 14688-2, ČSN 73 6133 and also according to the original ČSN 72 1001.

■ **The analysis of water leach of soils** focuses on determining the amount of leached Ca^{++}, Mg^{++}, Na+, K+, Fe^{++}, Mn^{++}, SO^{4}++, Cl^{-}, NO^{3-}, HCO^{3-}, eventually CO^{3--}. The results refer to mineralization of 1 litre distilled water by 100 g of mushed soil, or to % content of individual soluble components in 100 g of soil. Fraction smaller than 1 mm is used for the preparation of leach. The ratio of distilled water to air-dried soil is 5 : 1.

■ **The reaction of soils (pH)** is specified as active reaction pH/H2O on the one hand, and as exchange reaction pH/KCl on the on the other hand. The pH values are measured electrometrically in water suspension (pH/H2O) or in soil suspension in 1N solution of potassium chloride (pH/KCl). The ratio of distilled water or 1N solution of KCl to air-dried soil is 5 : 1.

■ **Water analyses** are focused on determination of main components that may aggressively affect the concrete structures. Individual components are determined methods that are described in detail in the paper Particular Methods of Chemical Water Analysis. Concentration of ions Na+, K+, Fe++, Mn++ was determined by atomic absorption spectrophotometry using the instrument VARIAN 250 PLUS.

■ **Oedometric deformation modulus** E_{oed} (MPa) is determined by laboratory test of compressibility in an oedometer according to ČSN CEN ISO/TS 17892-5.

■ **Swelling pressure CT**sw **(kPa)** is determined by laboratory test in an oedometer according to ČSN CEN ISO/TS 17892-5.

■ **Parameters shear strength** - **cohesion c** (kPa) and **angle of internal friction** ^ (°) - are determined by laboratory direct test according to ČSN CEN ISO/TS 17892-10. Tests were executed as drained and the results are of the nature of effective parameters of peak shear strength. The time of consolidation and advance rate of the shear box were adjusted to structural nature of the sample

■ **Index strength at point load** was determined by crushing irregular chips of the rock mass in manual press in accordance with original ON 44 1119 (already annulled now) and ČSN P ENV 1997-2. The simple pressure strength of the rock mass CTG (MPa) is approximately determined from the resulting value of index strength I50 (MPa) by means of empirically ascertained coefficient.

■ Abrasiveness of rocky stone masses is determined by the CERCHAR METHOD at surface sample modified by a saw. The tip hardness HRC 55 and microscope magnification 4.5 were selected. The following classification was interpreted for assessment of results (always 10 parallel measurements):

Tab. 4.2.a Classification of rock mass abrasiveness according to CAI (ASTM D7625-10:2010)

Klasifikace abrazivnosti	CAI (HRC=55)
velmi nízká	0,30 - 0,50
nízká	0,50 - 1,00
střední	1,00 - 2,00
vysoká	2,00 - 4,00
extrémně vysoká	4,00 - 6,00
kvarcitická	6,00 - 7,00

- **Pressiometric tests** were carried out at unsupported walls of core boreholes 76 mm diameter using the apparatus of the French company MÉNARD, type GA with radial pressure range of 8 MPa and the survey boreholes type NX of 74 mm diameter.
- **Dilatometry tests** were executed at unsupported walls of core boreholes of 76 mm diameter using the exploration well PROBEX from the Canadian manufacturer ROCTEST.

4.3. RESULTS OF TESTS AND THEIR ASSESSMENT

4.3.1. Basic physical properties of soils

Results of total 33 executed tests of basic physical properties of soils (granular composition, natural humidity, consistency limits etc., eventually specific gravity, too) are in detail documented in the complex table summary and individual protocols in annex No. 5 of this report. In case of individual geotypes, characteristics and classifying categorisation specified below in table 4.3.1.a. were ascertained (after completing by archive measurement).

Tab. 4.3.1.a: Interpretation of results of basic soil properties for the classifying categorisation (detailed breakdown of geotypes)

stratigraphic formation and genetic complex		geotype / symbol of the strata and degree of weathering		volume weight in natural bedding γ ($kN.m^{-3}$)	filtration coefficient k_f ($m.s^{-1}$)	categorization according to ČSN P 73 1005 and ČSN 73 6133
Quarternary sediment recent	made-grounds	An	undifferentiated	18.0	10^{-6}	Y
Quarternary sediment Pleistocene	eolian and eolian-diluvial sediments	Eol1	loam with or even medium plasticity	20.0	10^{-8}	MI, CI
		Eol2	loams or even sandy clay	18.0	10^{-8}	MS, CS
	deluvial sediments with chips of Cretaceous rock	Dl1	loam or even gravel clay	19.5	10^{-7}	MG, CG
		Dl2	loam or even sandy clay	18.5	10^{-8}	MS, CS

stratigraphic formation and genetic complex		geotype / symbol of the strata and degree of weathering		volume weight in natural bedding γ ($kN.m^{-3}$)	filtration coefficient k_f ($m.s^{-1}$)	categorization according to ČSN P 73 1005 and ČSN 73 6133
	masses	Dl3	loam or even clay with medium plasticity	20.5	10^{-8}	MI, CI
		Dl4	loamy and clayish gravel	19.5	10^{-7}	GM, GC
	diluviofluvial sediments	Dfl1	loamy sand or even clayish sand	18.5	10^{-7}	SM, SC
		Dfl2	loam or even sandy clay	19.0	10^{-7}	MS, CS
		Dfl3	loam or even clay with medium plasticity	21.0	10^{-8}	MI, CI
	fluvial sediments	Fl1	sand with admixture of fine grain soils	18.0	10^{-5}	S-F
		Fl2	loamy sand or even clayish sand	19.0	10^{-7}	SM, SC
		Fl3	gravel with admixture of fine grain soil	19.0	10^{-5}	G-F
		Fl4	loamy or even clayish gravel	19.5	10^{-7}	GM, GC

4.3.2. Shear strength

Three non-disrupted samples of soils were subject to laboratory tests of shear strength. Tests were executed as drained and the results are of the nature of effective parameters of peak shear strength. The results ascertained below were specified at the tests.

Deluvial sediment – HJ8, depth 1.8-2.1 m, S5/SC - clayish sand
geotechnical type Dl2

consistency	(incohesive)
cohesion (kPa)	c_{ef} = 4.7
angle of internal friction (°)	ϕ_{ef} = 33.8
specific gravity in natural bedding	ρ = 2123 kg.m-3

Deluviofluvial sediment – HJ1, depth 29.0-29.3 m, F6/CI clay with medium plasticity
geotechnical type Dfl3

consistency	rigid
cohesion (kPa)	c_{ef} = 27.0
angle of internal friction (°)	ϕ_{ef} = 25.9
specific gravity in natural bedding	ρ = 2220 kg.m-3

Eolian sediment – PJ13, depth 8.0-8.3 m, F6/CI - clay with medium plasticity geotechnical type Eol

consistency	**rigid**
cohesion (kPa)	c_{ef} = 18.7
angle of internal friction (°)	ϕ_{ef} = 19.2
specific gravity in natural bedding	ρ = 1940 kg.m-3

Deluviofluvial sediment – PJ13, depth 11.7-12.0 m, F6/CL - clay with low plasticity, geotechnical type Eol

consistency	solid
cohesion (kPa)	c_{ef} = 29.3
angle of internal friction (°)	ϕ_{ef} = 20.9
specific gravity in natural bedding	ρ = 2090 kg.m-3

Deluvial sediment – PJ13, depth 4.3-4.6 m, F4/CS - sandy clay geotechnical type Dl2

consistency	**rigid**
cohesion (kPa)	c_{ef} = 19.7
angle of internal friction (°)	ϕ_{ef} = 22.9
specific gravity in natural bedding	ρ = 2080 kg.m-3

Deluviofluvial sediment – PJ13, depth 18.0-18.3 m, F4/CS - sandy clay geotechnical type Dfl3

consistency	solid
cohesion (kPa)	c_{ef} = 27.1
angle of internal friction (°)	ϕ_{ef} = 22.8
specific gravity in natural bedding	ρ = 2090 kg.m-3

Fluvial sediment – PJ13, depth 28.2-28.5 m, F4/CS - sandy clay geotechnical type Fl2

consistency	solid
cohesion (kPa)	c_{ef} = 28.0
angle of internal friction (°)	ϕ_{ef} = 23.3
specific gravity in natural bedding	ρ = 2030 kg.m-3

Made-grounds – HPJ12, depth 8.0-8.3m, F4/CS - sandy clay geotechnical type An

consistency	rigid
cohesion (kPa)	c_{ef} = 21.9
angle of internal friction (°)	ϕ_{ef} = 23.2
specific gravity in natural bedding	ρ = 1930 kg.m-3

Deluviofluvial sediment – HPJ12, depth 12.0-12.3 m, F4/CS - sandy clay geotechnical type Dfl2

consistency	solid
cohesion (kPa)	c_{ef} = 32.9
angle of internal friction (°)	ϕ_{ef} = 23.1
specific gravity in natural bedding	ρ = 2050 kg.m-3

Deluviofluvial sediment – HPJ12, depth 17.7-18.0 m, F4/CS - sandy clay geotechnical type Dfl2

consistency	solid

cohesion (kPa)	c_{ef} = 24.9
angle of internal friction (°)	ϕ_{ef} = 22.2
specific gravity in natural bedding	ρ = 1940 kg.m-3

Deluviofluvial sediment – HPJ12, depth 23.7-24.0 m, F4/CS - sandy clay geotechnical type Dfl2

consistency	solid
cohesion (kPa)	c_{ef} = 31.5
angle of internal friction (°)	ϕ_{ef} = 23.0
specific gravity in natural bedding	ρ = 2090 kg.m-3

Fully weathered (decomposed) – PJ9, depth 3.0-3.2 m, F4/CS - sandy clay geotechnical type Dbr/W5

consistency	solid
cohesion (kPa)	c_{ef} = 51.3
angle of internal friction (°)	ϕ_{ef} = 24.2
specific gravity in natural bedding	ρ = 2315 kg.m-3

The ascertained results very well correspond to the geological nature of the tested soils and are fully in accordance also with the results of archive tests of stratigraphically, genetically and structurally similar materials. They represented, together with the database of archive results, the background data for determination of the shear strength parameters of soils in the table of recommended geotechnical characteristics in Chapter 8.2.

4.3.3. Compressibility and swelling pressures of soils

Compressibility of soils was verified in an oedometer for **two** taken non-disrupted **samples** and the swelling pressure for **one** of them. Following results were ascertained at the tests:

eolian sediment - loess – CS sandy clay of rigid consistency

oedometric modulus (for load 150 - 250 kPa)	E_{oed} = 8.4 MPa
time coefficient of consolidation	c_v = 8.203 .10-9 m2.s-1
swelling pressure	σ_{sw} = 0.00 MPa (soil does not swell)

buried soil horizon in loesses – humous CI clay with medium plasticity of rigid consistency

oedometric modulus (for load 150 - 250 kPa)	E_{oed} = 15.0 MPa
time coefficient of consolidation	$c_v = 2.702 .10^{-9}\ m^2.s^{-1}$

The ascertained results very well correspond to the geological nature of the tested soils and are in accordance also with the results of archive tests of stratigraphically, genetically and structurally similar materials. They represented, together with the database of archive results, the background data for determination of the deformation parameters of soils in the table of geotechnical characteristics in Chapter 8.3.

4.3.4. Sinkability of soils

Sinkability of soils was verified in an oedometer for **two** taken non-disrupted **samples** with following results:

eolian sediment - loess – CI clay with low plasticity, solid consistency
sinking by 0.18 mm

	0.91 %
Soil evaluation	**NON-SINKABLE**

eolian sediment - loess – CI clay with low plasticity, solid consistency

sinking by	**0.05 mm**
	0.25 %
Soil evaluation	**NON-SINKABLE**

The ascertained results very well correspond to the geological nature of the tested soils and are in accordance also with the results of archive tests of stratigraphically, genetically and structurally similar materials***. The sinking was smaller than 1% in case of both samples, which is a criterion usual for categorization among sinkable soils.***

4.3.5. Determination of carbonates content

The content of carbonates was verified for **two** taken disrupted **samples** a following results were ascertained at the analysis:

Exploration well HJ1
eolian sediment - loess – CI clay with medium plasticity
Carbonates content 12.6%

Exploration well PJ13
eolian sediment – loess loam – CI clay with medium plasticity
Carbonates content 12.3%

The content of calcific component (stringers) of this value is for Prague eolian sediments (loesses) quite usual.

4.3.6. Basic physical and strength characteristics of rocky stone masses

Detailed results of **basic physical and strength characteristics of** rocky (semi-rocky) stone masses are in detail documented in the complex table summary and individual protocols in annex No. 5 of this report. Laboratory **single axis pressure tests** at cylindrical bodies are dominant here above all, with specification of respective specific gravities (moist and dry) and natural humidity. Tests of **index strength of rock masses** (of subsidiary importance here).

The **categorisation of rocky stone masses** is based on single-axis compressive strength according to ČSN 73 6133 and ČSN P 73 1005, as per the respective intervals:

Interval of single axis compression strength	*σc [MPa]*	*class of strength classification*
›150	R 1	very high
50 - 150	R 2	high
15 - 50	R 3	medium
5 - 15	R 4	low
1.5 - 5	R 5	very low
0.5 - 1.5	R 6	extremely low

The respective R categorisations are specified in the following tabular overview for individual weathering degrees. Results of compressive strength from samplings in the second half of the route from Palaeozoic rock masses of Letn**á and Dobrotivian series of strata** are ***substantially lower*** compared to the central part of Prague (adjacent to Vltava river channel above all). This is caused by different petrography and probably by the altitudinal position as well as – it is higher in the modernization route compared to the Vltava riverbank. On the healthy horizon of the Dobrotivian shale, for example, the strength is average.

Tab. 4.3.6.a: Interpretation of results of basic rock mass properties for classifying categorisation

stratigraphic formation and genetic complex		geotype / symbol of the strata and degree of weathering		volume weight in natural bedding γ ($kN.m^{-3}$)	filtration coefficient k_f ($m.s^{-1}$)	categorization according to ČSN P 73 1005 and ČSN 73 6133
Paleozoic Ordovician Letná series of strata	silty shales and greywacke sandstones	Ltn/W5-W4	fully or even heavily weathered	18.5	$10^{-6} – 10^{-8}$	R6
		Ltn/W3	slightly weathered	22.0	$10^{-8} – 10^{-9}$	R5
		Ltn/W2	weakly weathered	25.0	10^{-9}	R4
		Ltn/W1	sound	25.5	10^{-9}	R3
		Ltn/TEKT	tectonically disrupted	24.0	10^{-6}	R5-R4
Paleozoic Ordovician of Dobrotivian series of strata	silty shales	Dbr/W5-W4	fully or even heavily weathered	20.5	10^{-7}	R6
		Dbr/W3	slightly weathered	22.0	10^{-7} - 10^{-8}	R5
		Dbr/W2	weakly weathered	25.0	10^{-8}	R4
		Dbr/W1	sound	26.0	10^{-9}	R4
		Dbr/TEKT	tectonically disrupted	24.5	10^{-7}	R5
Mesozoic upper chalk – turon, Bílá Hora ss.	sandy marlstones (sandy marls)	KT	weakly weathered or even sound	22.0	10^{-7}	R3
Mesozoic upper chalk – cenoman, Peruc-Korycany strata	fine grain quartz sandstones	KCp	sound	19.5	10^{-6}	R5
	claystones or even siltstones	Kcj	sound	21.0	10^{-9}	R6

The ground surface is now situated in the specified end part of the route at the altitude of 300 to 350 m a.s.l. and the Palaeozoic rocky stone masses were affected by very deep freezing in the geological past of ice-ages. However, even older influences took effect here probably – pre-Cretaceous fossil weathering. Effects of these impacts are not apparent in the detailed geological documentation (colours are dark grey to black). However, the geotechnical characteristics are slightly changed even at the level of basic rock material. Specific gravity is decreased, humidity increased and it became evident especially on the solidity that is significantly smaller. It is not a sound but very weakly weathered material from the viewpoint of aspects of rock mass mechanics.

4.3.7. Abrasiveness of rocky stone masses

Abrasiveness of rock masses was verified by the CERCHAR method for eight samples taken from sound horizon of Palaeozoic rock mass with the following results (always 10 parallel measurements),arranged from the bottom beginning part of the route and assessed according to the following abrasiveness classification CAI (HZC-55):

Tab. 4.3.7.a: Classification of rock mass abrasiveness according to CAI (ASTM D7625-10:2010)

Klasifikace abrazivnosti	CAI (HRC=55)
velmi nízká	0,30 - 0,50
nízká	0,50 - 1,00
střední	1,00 - 2,00
vysoká	2,00 - 4,00
extrémně vysoká	4,00 - 6,00
kvarcitická	6,00 - 7,00

Borehole J 3, depth 42.3 – 43.0 m, sample No. 19 / 19

Libeň series of strata, W 1 – sound clay-silty shale, R 3

Result CAI 0.77 classification: **LOW ABRASIVENESS**

Borehole HPJ 4, depth 16.1 – 16.6 m, sample No. 1917 / 18

Letná series of strata (monotonous development), W 1 – sound sand-silty shale, R 5

Result CAI 0.76 classification: **LOW ABRASIVENESS**

Borehole HPJ 4, depth 34.5 – 36.0 m, sample No. 1918 / 18

Letná series of strata (monotonous development), W 1 – sound lamina of fine grain quartzites, R 2

(the induced compressive strength of 80.6 and 104.2 MPa was determined in case of this rock mass according to the ascertained index at point load)

Result CAI 4.42 classification: **EXTREMELY HIGH ABRASIVENNES**

Borehole PJ 7, depth 79.2 – 79.6 m, sample No. 1957 / 18

Letná series of strata (flysch mood of evolution), W 1 – sound silty shale, R 4

Result CAI 0.85 classification: **LOW ABRASIVENESS**

PJ 9, depth 23.5 – 24.0 m, sample No. 1820 / 18

Dobrotivian series of strata, W 1 – sound silt-clayish shale, R 5

Result CAI 0.68 classification: **LOW ABRASIVENESS**

Borehole HJ 11, depth 80.1 – 80.6 m, sample No. 56 / 19

Dobrotivian series of strata, W 1 – sound silty shale R 4

Result CAI 0.91 classification: **LOW ABRASIVENESS**

Borehole PJ 14, depth 40.4 -41.8 m, sample No. 16543

Letná series of strata (flysch mood of evolution), W 1 – sound silty shale, R 3

Result CAI 0.97 classification: **LOW ABRASIVENESS**

Borehole PJ 14, depth 46.3 -48.0 m, sample No. 16544

Letná series of strata (flysch mood of evolution), W 1 – sound silty shale, R 3

Result CAI 1.03 classification: **MEDIUM ABRASIVENNES**

Borehole HJ 15, depth 41.0 -42.4 m, sample No. 68959

Letná series of strata (flysch mood of evolution), W 1 – weakly weathered silty shale, R 3/R 4

Result CAI 0.76 classification: **LOW ABRASIVENESS**

Borehole HJ 15, depth 45.3 -47.0 m, sample No. 68960

Letná series of strata (flysch mood of evolution), W 1 – weakly weathered silty shale, R 3/R 4

Result CAI 0.74 classification: **LOW ABRASIVENESS**

Borehole HJ 15, depth 47.5 -48.9 m, sample No. 68961

Letná series of strata (flysch mood of evolution), W 1 – weakly weathered silty shale, R 3/R 4

Result CAI 0.87 classification: **LOW ABRASIVENESS**

Borehole HJ 16, depth 72.0 -74.0 m, sample No. 68956

Letná series of strata (flysch mood of evolution), W 1 - weathered sand-silty shale or even fine grain sandstone, R 3/R 4

Result CAI 1.39 classification: **MEDIUM ABRASIVENNES**

Borehole HJ 16, depth 76.7 -78.7 m, sample No. 68957

Letná series of strata (flysch mood of evolution), W 2 - slightly weathered shale with sandy positions, R 4/R 5

Result CAI 0.66 classification: **LOW ABRASIVENESS**

Borehole HJ 16, depth 80.0 -82.0 m, sample No. 68958

Letná series of strata (flysch mood of evolution), W 2 – weathered sandy shale, R 4

Result CAI 0.90 classification: **LOW ABRASIVENESS**

It can be summarized in conclusion of this part of assessing geotechnical properties of rocky stone masses that **EXTREMELY HIGH ABRASIVENNES** (CAI 4.42) was ascertained only in case of Letná series of strata, of monotonous development, W 1 – sound lamina fine grain quartzites, R 2. **MEDIUM ABRASIVENNES** (CAI 1.03 and 1.39)was ascertained in case of two samples. It was a sample with higher share of fine grain microscopic quartz component (approximately Ø 55%). In case of all other samples, average values of CAI were ascertained in narrow interval of 0.66–0.97 with identical **LOW ABRASIVENNES** classification.

4.3.8. Petrographic analysis of rocky stone masses

In total 7 samples were taken within the geotechnical investigation for the purpose of conducting petrographic analysis. Based on micro-petrologic observation The taken samples were divided into following rock mass types:

silty shale – clayish siltstone (shales of Letná, Libeň, and Dobrotivian series of strata – Ordovician)

fine grain greywacke sandstone with carbonate binder (sandstone insertion in rock masses of the Letná series of strata)

fine grain clayish sandstone with clay-silty basic substance, dark black-grey, non-carbonate (transition from sandstones to silty shales in rock masses of the Letná series of strata)

4.3.9. Field pressiometric tests

We summarize an overview of pressiometric characteristics ascertained in individual tested boreholes in the following table:

Tab. No. 4.3.1.a. Summary of ascertained pressiometric characteristics

exploration well (depth)	test No.	depth (m)	tested material	pressiometric deformation modulus	pressiometric elastic modulus	yield limit pressure pf (MPa)	limit pressure pL(MPa)
PJ-02 (40 m)	1	9.7	loess loam, rigid or even solid	10.1	-	0.603	1.10
	2	13.7	loess loam, rigid or even solid	12.3	-	0.643	1.24
	3	18.2	outwash loam with gravel, solid	19.0	-	0.987	1.69
	4	21.7		16.4	-	0.821	1.52
	5	24.2		19.3	-	1.05	1.95
	6	29.7		55.5	-	1.66	2.96
HPJ-04 (60 m)	7	10.7	shale sand-silty, sound, tectonically disrupted (class	168	-	2.51	4.91
	8	20.7	shale sand-silty, sound, weakly tectonically disrupted (class R5)	240	-	3.21	7.21

exploration well (depth)	test No.	depth (m)	tested material	pressiometric deformation modulus	pressiometric elastic modulus	yield limit pressure pf (MPa)	limit pressure pL(MPa)
	9	**26.7**	sand-silty shale, sound (class R3/R2)	**375**	-	**>8.00**	**>10.0**
	10	**33.3**		**398**	-	**>8.00**	**>10.0**
	11	**41.7**		**552**	-	**>8.00**	**>10.0**
	12	**45.7**		**596**	-	**>8.00**	**>10.0**
PJ-07 (94 m)	**13**	**9.7**	sandstone, weakly lihificated (class R6)	**55.2**	-	**1.21**	**2.41**
	14	**24.5**	claystone, weakly silty (class R6)	**71.3**	-	**1.81**	**3.21**
	15	**34.2**	clay-sandy shale, fossil weathered (class R5)	**198**	-	**3.21**	**6.61**
	16	**44.7**	clay-sandy shale, sound (class R3/R2)	**775**	1137	**>8.00**	**>10.0**
	17	**54.7**		**596**	-	**>8.00**	**>10.0**
	18	**59.7**	clay-sandy shale, sound, weakly tectonically disrupted (class R4/R3)	**521**	-	**>8.00**	**>10.0**
	19	**64.7**	clay-sandy shale, sound (class R3/R2)	**756**	1109	**>8.00**	**>10.0**
	20	**69.7**		**631**	-	**>8.00**	**>10.0**
	21	**74.7**	clay-sandy shale, sound, weakly tectonically disrupted (class R4/R3)	**560**	893	**>8.00**	**>10.0**
	22	**79.7**		**408**	-	**>8.00**	**>10.0**
	23	**84.7**		**479**	-	**>8.00**	**>10.0**
	24	**89.7**	clay-sandy shale, sound (class R3/R2)	**960**	1611	**>8.00**	**>10.0**
<-09 (34 m)	**25**	**6.2**	sand-silty shale, slightly weathered, tectonically disrupted (class R6/R5)	**51.2**	-	**1.01**	**2.21**
	26	**10.2**		**62.8**	-	**1.21**	**2.41**
	27	**14.2**	silt-clayish shale, sound tectonically disrupted (class R5/R4)	**98.7**	-	**1.61**	**2.81**
	28	**18.2**		**111**	-	**1.61**	**3.01**
	29	**22.1**	silt-clayish shale, sound weakly tectonically disrupted (class R4)	**226**	-	**2.71**	**6.41**
	30	**27.7**		**271**	-	**4.01**	**>8.00**
HPJ12 (32 m)	**1**	**7.7**	Made-ground – character of sandy loam	**39**	-	**0.88**	**1.88**
	2	**15.7**	loam with medium plasticity	**42**	-	**1.06**	**1.96**
PJ13 (36.2 m)	**3**	**9.0**	Gravel loam, chips of sandy marl	**24**	-	**0.70**	**1.30**
	4	**16.2**	Clay with medium plasticity, chips of shale	**37**	-	**1.07**	**1.97**

Note: *The pressures PF=8.00 MPa resp. pL=10.0 MPa represent the maximum range of the instrument and the actual values can be higher.*

Measured values of pressiometric characteristics are in accordance with nature of the tested, overall extraordinary heterogeneous geological environment - **quarternary sediment of eolian and deluviofluvial sediments of** predominantly solid consistency, found over the whole length of the core borehole PJ-02, weakly lihificated **upper Cretaceous sandstones and claystones of** Peruc-Korycany series of strata (cenoman) in the upper storey of the borehole PJ-07, most frequently represented by Ordovician **sand-silty or clay-sandy shales of Letná series of strata** in flysch or monotonous development (borehole HPJ-04 or basal storey borehole PJ-07) and also **silt-clayish shales of Dobrotivian series of strata** (over the whole length of the borehole PJ-09).

The rockbed of Ordovician shales is partly affected by **tectonic disruption** and locally also by fossil weathering and the results of tests document concisely the negative influence of these documented disturbances on geotechnical properties of rock environment. However, **gradual in-depth growth of the strength and deformation parameters of the rock massif is also very clearly apparent owing to decreasing degree of weathering and blistering** at the same time

4.3.10. Field dilatometric tests

In total 13 dilatometric tests were executed in boreholes PJ-14, HJ15, and HJ16. Rock masses of Letná series of strata were the tested environment. We summarize ascertained dilatometric characteristics in the following table:

exploration well (depth)	test No.	depth (m)	tested material	dilatometric deformation modulus E_d (MPa)	limit pressure p_L(MPa)
J14	1	30	Slightly weathered shale, fissured here and there, R4	1863	103
	2	36.5	Slightly weathered shale, fissured here and there, R4	1592	79
	3	42.5	Slightly weathered shale, fissured here and there, R4	3970	139
	4	46	Shale fully weathered, tectonic disturbance, R6	1808	50
	5	52	Weakly weathered shale, R4	7658	-
	6	56	Weakly weathered shale, R4	7776	-
	7	59	Weakly weathered shale, R4	7540	-
HJ15	4	46	Weakly weathered shale, R4/R5 silty, weakly fissured	74	3.6
	5	40	Weakly weathered shale, R4/R5, silty, weakly fissured	71	3.5
	6	34	Weakly weathered shale, R4/R5, heavily weathered here and there, R5, silty, weakly fissured	20	2.0
HJ16	1	75	Siltstone, weakly weathered, weakly fine sandy, R4 (with positions of weakly weathered shales of R6 class)	208	5.0
	2	72	Siltstone, weakly fine sandy, R4/R5	324	7.5
	3	65	Shale, sound, silty, R4/R5	148	5.5

Pressure higher than 25 MPa was reached was in the borehole PJ-14 at dilatometric tests in total 5 of 7 measurements, whereas the tests No. 5-7 reached pressure over 29 MPa. Ascertained results correspond to geological nature of the tested rock masses (shales of the weathering degree w2 – w3). The measured value of dilatometric modulus E_d grows with depth almost linearly. An exception is represented by the value measured in the depth of 46 m (test No. 4, shale w5) that corresponds to ascertained position of a tectonic disturbance, however. The expected value of dilatometric modulus E_d was lower at this tectonic disturbance prior to the measurement beginning, nevertheless, it is necessary to assess objectively the measurement circumstances – the tectonic disturbance is approximately 60 cm thick, whereas active measuring part of the membrane of dilatometric exploration well is 45.7 cm long. It is very difficult in common practice to reach a depth with exactness of units of centimetres or the position of cores in sample containers is not so perfectly exact usually. That is why the active part of the exploration well (measuring membranes) leaned partly against the rock mass material above or below this tectonic disturbance and partly directly against the rock mass material of the tectonic disturbance probably at the measurement. Though the measured value E_d reflects this rock mass inhomogeneity quite clearly, the actual value will be even lower probably.

E_d values increase with the depth in HJ15 borehole, even though the difference among positions 40-46 m is minor only. The value measured in the depth of 34 m was lower than expected in the given horizon. The cause of this unusually low value is the influence of nearby, heavily weathered (W4) and tectonically disrupted shale position probably. Presumably, this value does not represent the profile value in the depth of 23.8 – 36 m; the assumed E_d value of this profile will be probably very similar to the remaining measured values, i.e. within the range of approximately 60-70 MPa.

The tests in the HJ16 borehole reached wider profile of geological materials and the dispersion of values is larger in individual depths. The value measured in the depth of 65 m corresponds to W1 sound shale. Higher value was measured in the depth of 72 m (W2 siltstone), it fully corresponds to weathered siltstone though. The value of 208 MPa from 75 m depth shows a considerable decline compared to the previous value, even though both were measured in the same geological profile. This decline is put down to the influence of weakly weathered W2 shales in the depth of 74.7-76.15 m – the probe leant partly on this weakly weathered shale position and partly on W2 sandstone position probably, the result of which is the resulting value.

5. HYDROGEOLOGICAL MEASUREMENT

5.1. HYDRODYNAMIC TESTS

Acquiring information on resistance characteristics watterlogged rock mass environment and determination of hydraulic conductivity of the tested rock mass environment was the purpose of hydrodynamic tests.

Hydrodynamic tests were carried out at the newly executed equipped exploration HG boreholes HJ1, HJ4 and HJ8 for the purpose of evaluating hydraulic properties of geological environment within the preliminary hydrogeological survey of the whole route. The borehole HPJ12 was executed only as an observation borehole, pumping tests cannot be carried out in it for reasons of groundwater table sank to the borehole base. Furthermore, archive data from pumping tests executed at archive monitoring boreholes HRA-1 and HRA-2 were newly evaluated (data taken over from Bureš, Gardavská 2013). Logging tests were conducted at the newly executed survey borehole J11 with respect to definitive diameter of its equipment (tests were carried out by RNDr. Svatopluk Kořalka, AQUATEST a.s , logging centre, 2019).

Basic parameters of tested boreholes are specified in the Technical Report on Drilling attached to the summary report of the preliminary geotechnical investigation.

Express pumping tests were carried out in the regimen of unsettled streaming at boreholes HJ1, HJ4 and HJ8 with subsequent rising test. The pump was immersed approximately 10 m above the borehole bottom. A constant water amount of Q = 0.6 to 1.0 l/s was pumped from boreholes using the pump Grundfos SQ2-70. Rising tests were carried out subsequently after completion of the pumping tests, during which elevated groundwater table was monitored.

It was not possible to sink the groundwater table to the level of the tunnel bottom lining by the pumped amount of Q= 1.0 l/s with respect to relatively strong groundwater inflow especially to the borehole HJ4 and also HJ8. Therefore, we recommend based on the submitted results to propose and, in case of approving opinion of the water right authority, also to carry out pumping tests with sinking the water table to several depressions in the further survey phase (pumped amount of Q > 1.0 l/s must be taken into consideration).

No precipitations were registered in the course of performing hydrodynamic tests, pumped water was drained to sufficient distance, so that streaming was not affected within the borehole range.

Pumping and rising tests were evaluated by appropriate graphic-analytic methods using the program AquiferTest For 7.0. The graphic curve, documentation and evaluation of hydrodynamic tests are specified in annex No. 4 of this report.

Values of the coefficient of hydraulic conductivity (filtration coefficient) k for the given rock mass environment and transmissivity coefficient T, ascertained based on executed tests are specified in the following table No. 6. The results of newly executed hydrodynamic tests were used for evaluation of hydraulic (filtration) parameters of the geological environment, as well as values taken over from archive surveys. Values of hydraulic conductivity coefficient (filtration coefficient), verified based on logging measurements in the borehole J11, are taken over from the evaluation of the logging tests by their executor (RNDr. Svatopluk Kořalka, AQUATEST a.s, logging centre).

Strong inflows were found in 5.4-6.0 m, 15.6-16.7 m, and 17.2-17.7 m depths in the HJ15 borehole carried out newly. Weaker inflows were found in 12.5-13.3 m and 19.7-20.0 m depths. Groundwater horizons occurring deeper could not be found, there was an accident in 21.5 m depth of bore – it was not passable for the measuring equipment. Strong inflows were found in 30.0-30.6 m, 33.0-34.1 m, 36.0-36.5 m, 42.5-43.0 m depths were found in HJ16 borehole by logging measurement. Weaker inflows were found in 49.5-50.0 m, 54.0-54.4 m, 58.1-58.7 m, 60.0-60.4 m, and 69.4-70.0 m depths.

Tab. No. 5.1.a. - Hydraulic parameters of the rock mass environment

tested structure	**coefficient of hydraulic conductivity - k**	**coefficient of transmissivity - T**	**Note**
	$m.s^{-1}$	$m^2.s^{-1}$	
HJ1	*$8.7.10^{-7}$	*$3.5.10^{-6}$	quarternary collector - sand to gravel clayish, Dejvice terrace
HPJ4	1.10^{-5} *$2.0.10^{-5}$	$8.3.10^{-5}$ *$1.6.10^{-4}$	Letná series of strata - shale silty sound, tectonically disrupted
HJ8	$5.5.10^{-6}$ *$2.0.10^{-5}$	$2.5.10^{-5}$ *$4.4.10^{-6}$	Dobrotivian series of strata - shale silt-clayish sound, tectonically disrupted

tested structure	coefficient of hydraulic conductivity - k	coefficient of transmissivity - T	Note
	$m.s^{-1}$	$m^2.s^{-1}$	
HJ11	***$1.1.10^{-7}$	-	Letná series of strata - shale silty sound, fissured here and there
PJ14	***$5.5.10^{-8}$	-	Letná series of strata - shale silty sound, fissured here and there
HJ15	***2.10^{-7} - 3.10^{-8}	-	Letná series of strata - silty shale, strongly or even slightly weathered, strongly fissured
HJ16	***6.10^{-8}	-	Letná series of strata - shale silty sound, fissured here and there
HRA-1	6.10^{-5}	3.10^{-4}	quarternary collector - clayish sand, clayish sand with gravel
HRA-2	7.10^{-6}	2.10^{-5}	quarternary collector - loamy sand
HF-9/P022816	**$7.4.10^{-4}$	-	quarternary collector - Dejvice terrace

) values calculated from rising tests, **) archive values taken over, *) values taken over from the evaluation of logging measurement*

5.2. SAMPLING AND HYDROCHEMICAL EVALUATION

Values of electric conductivity, temperature and pH of water were monitored in parallel with groundwater sampling. Results of measurements carried out are specified in the following table 7. Differences between values measured in the field and in the laboratory are caused by changes in a sample during transport and storing.

Tab. No. 5.2.a – Results of field measurement of groundwater quality

	date of measurement	water table at sampling (m under ground level)	PH	T (°C)	conductivity (pS/cm)
HJ1	13/12/2018	38.50	7.63	4.5	1539
HPJ4	14 Jan. 2019	7.15	7.20	11.7	1204
HJ8	15 Jan. 2019	18.00	7.56	11.1	554

Groundwater analysis was performed at the groundwater sample from the borehole HJ4 (collector of Ordovician shales) in the scope of complete chemical analysis for determination of natural chemism of groundwater was within the preliminary geotechnical investigation.

Results of newly executed analyses groundwater were compared with limits and limit values in terms of the Decree No. 252/2004 Coll. Over-limit values are highlighted by bolt font in the table. Complete results of laboratory analyses are specified in annex No. 5.

Tab. No. 5.2.b Results of chemical analyses

Name of indicator	limit value (Decree 252/2004 Coll.)	HPJ4

Name of indicator	**limit value (Decree 252/2004 Coll.)**	**HPJ4**
pH	6.5-9.5	6.91
conductivity pS/cm	1250 pS/cm	**1720**
KNK 4.5	- (mmol/l)	4.23
total hardness	- (mmol/l)	5.65
sodium decomp.	200 mg/l	61.8
potassium decomp.	- (mg/l)	5.35
ammonium ions	0.5 mg/l	0.188
ammoniac nitrogen	- (mg/l)	0.146
calcium decomp.	30 mg/l 1)	150
magnesium decomp.	10 mg/l 1>	46.4
sulphates	250 mg/l	**298**
chlorides	100 mg/l	**247**
nitrites	0.50 mg/l	<0.0050
nitrates	50 mg/l	<2.00
fluorides	1.5 mg/l	1.02
phosphates	3.5 mg/l	<0.040
CHSK-Mn	3.0 mg/l	**3.44**
Sum of cations	- (mg/l)	264
Sum of anions	- (mg/l)	804
hydrogen carbonates	- (mg/l)	258
RL dried (105°C)	- (mg/l)	1180
manganese decomp.	0.05 mg/l 2)	0.444
iron decomp.	0.20 mg/l 2)	0.361

1) it is applicable for water where the content of the given component is reduced by treatment, it does not show unfitness to drink of potable water (but the decree also determines recommended values of content of the given component)

2) the content of iron in potable water up to 0.50 mg/l and manganese up to 0.10 mg/l is the permitted limit in geological environment with higher concentration of manganese and iron

Groundwater chemism is of the type Ca-Na-(Mg)-Cl-HCO3-(SO4) with increased mineralization predominantly in the vicinity of the assessed route. Increased content of chlorides and sodium results probably from anthropogenous contamination (winter maintenance of roads and footways), the higher content of iron, manganese and sulphates is given by the natural geological environment (Palaeozoic shale - Ordovician).

Groundwater was predominantly detected as weakly aggressive for concrete in the respective territory, degree XA1 according to ČSN EN 206+A1 (see table No. 5.2.c).

Sulphate aggressiveness dominates.

Table No. 5.2.c. Results of chemical laboratory analyses of groundwater

Borehole	Sampling depth (m)	Degree of aggressiveness according to ČSN EN 206-1					Resulting degree of aggressivity
		SO_4^{2-} (mg/l)	pH (-)	CO_2aggr. (mg/l)	NH_4^+ (mg/l)	Mg^{2+} (mg/l)	
HJ1	-	162	7.33	0	0.056	64.4	**non-aggressive**
HPJ4	-	**336**	7.57	9.98	0.087	50.4	**XA1**
HJ8	-	34.2	7.32	7.02	0.111	20.0	**non-aggressive**
HPJ12	31.5	**290**	7.3	0	<0.1	73.8	**XA1**
Limits:	non-aggressive	< 200	> 6.5	< 15	< 15	< 300	
	XA1	≥ 200 and ≤ 600	≤ 6.5 and ≥ 5.5	≥ 15 and ≤ 40	≥ 15 and ≤ 30	≥ 300 and ≤ 1 000	
	XA2	> 600 and ≤ 3 000	5.5 and ≥ 4.5	> 40 and ≤ 100	> 30 and ≤ 60	> 1 000 and ≤ 3 000	
	XA3	> 3.000 and ≤ 6,000	4.5 and ≥ 4.0	>100 up to saturation	> 60 and ≤ 100	≥ 3 000 up to to saturation	

note: if two monitored chemical parameters reached the same evaluation category, vale in this values, they were categorized according to ČSN EN 206 to the following higher degree of agressivity.

5.3. HYDROGEOLOGICAL CERTIFICATE OF THE ROUTE

Natural groundwater streaming is influenced by underground services in shallow collector, in deeper collector by construction of the underground line A, and construction of the tunnel complex of the urban ring construction of the tunnel complex of the urban ring in the area of interest. The extent and nature of influencing the natural groundwater regimen by the construction of the tunnel complex of the urban ring and by extending the route of underground line A is not known presently, majority of the archive survey boreholes record the status prior to the construction of these significant tunnel buildings and results groundwater monitoring conducted in the course of and after completion of the construction are not known yet.

Mined tunnels Střešovice km 4.215 - 7.322

The tunnel leads in the section from the entrance portal to approximately km 4.590 through quarternary deluviofluvial deposits of the nature of loams and clays, sandy loams and clays, with positions of loam sands and loam gravels. Relatively thick deposits of eolian sediments were found by means of archive boreholes in their overburden, as well as anthropogenous made-grounds in smaller thicknesses. The tunnel will be mined further through Ordovician rock masses of Barrandian - Letná and Dobrotivian strata, weakly weathered or even sound, with notable tectonically disrupted zones.

Ordovician rock masses behave as hydrogeological massif with predominantly fissure permeability and slightly tense groundwater table. Groundwater circulates more lively only in the upper weathering and blistering zone (intrinsic-fissure permeability) and the circulation in deeper parts is tied to tectonically disrupted lines then. The thickness of more lively water logging linked to weathered and fissured rock masses of hydrogeological massif can be estimated approximately to 20 - 30 m based on newly executed and archive survey boreholes. However, groundwater streaming will occur in greater depths of tectonically disrupted zones and lines, too, (the HG collecting borehole HG_1753/P129146 at km 5.635 reached groundwater table in the depth of 33 m, 64 and 100 m under the ground level, the inflow to the borehole was estimated to be approximately 0.9 l/s (Jerie, R., 2010)).

More notable tectonic disturbances and probably greater groundwater inflows in them may be expected approximately at km 4.480-4.650, km 4.835-4.870 (borehole J14), at km 6.000 - 6.200 (borehole HJ15), at km 6,600 - 6.750, and near the exit portal approximately at km 7.250 - 7.322 based on newly executed and archive survey boreholes. However, reaching tectonic disturbances or lines cannot be ruled out also in other sections of the tunnel with respect to the density of covering the designed route by survey boreholes.

Settled level of groundwater table was found by the survey borehole J14 in the depth of 10.60 or 9.50 m under ground level in Ordovician rock masses of the route of the mined tunnel and will be slightly fluctuate depending on the season. Settled groundwater table was detected in the collector of Ordovician shales in the depth of 6.50 or 4.35 m under ground level by the boreholes J3 and HJ4 executed for the previous route.

The groundwater table was found by the HJ15 well in the depth of 8.20 m under ground level in the environment of heavily weathered, fissured rock masses. The settled table was measured at 5.23 m under the ground level on 10 June 2020 Seasonal oscillation is to be expected in the given environment within the first meter.

The groundwater table was found by HJ16 well in the depth of 29.00 m under ground level at the base of sandstones of Cretaceous age respectively in close overburden of claystones of Peruc layers. This collector was sealed off by mineral packing (bentonite) so that the draining of cretateous collector into the collector located deeper does not happen. This collector is bound to series of strata of Ordovician rock masses of Letná and Dobrotivian series of strata. The settled table was measured at 30.12 m under the ground level on 10 June 2020 Given the depth, it concerns water bound to basal parts of cretaceous sedimentary rock masses. Seasonal oscillation is to be expected in the given environment within the first ten of centimetres.

Settled groundwater table was ascertained in the collector of Ordovician shales in the depth of 14 m under ground level in the archive borehole HG_1753/P129146 (Jerie, R., 2010). The settled groundwater table fluctuates in the overburden of Cretaceous collector in first units of meters above the collector base (formed Peruc claystones); it was reached by the archive survey borehole J-13/P059834 in the depth of 21.40 m under the ground level.

The newly executed survey borehole HJ4 reached weathered or even sound Letná shales, tectonically disrupted from top. Permeability of this environment was verified by newly executed hydrodynamic tests and it can be characterized by the filtration coefficient kf = 2.10^{-5} m/s. An average filtration coefficient kf = 1.10^{-5} m/s for tectonically disrupted zones and an average filtration coefficient kf = 1.10^{-8} m/s for weakly weathered or even sound Ordovician rock masses (of hydrogeological massif) were taken into consideration for the guidance calculation of inflows to the tunnel.

Groundwater inflows into the designed tunnel mined in quarternary sediments, may be expected from locally suspended quarternary aquifers in the initial part approximately to km 4.590 (the estimated temporary inflow will be approximately 0.25 – 1.5 l/s). Groundwater inflows may be expected especially when passing through tectonically disrupted zones and lines in further section of the mined tunnel, the inflows will be in order up to 0.1 l/s for 50 m of the tunnel when passing through sound Ordovician rock masses. Initial groundwater inflows from tectonically disrupted zones may reach up to 20 l/s for 25 m of the tunnel according to expert estimation, sporadically to 30 l/s for 25 m of the tunnel, depending on the initial hydrostatic pressure and on the nature of the tectonic disruption (filling with clay). However, these initial inflows will turn weaker with evacuating static reserves and with decrease of hydrostatic pressure. Permanent inflow from tectonically disrupted zone to the tunnel may be considered in the order of approximately 2 - 5 l/s for 25 m of tectonically disrupted zone based on an expert estimate.

New deep bored wells and deep boreholes with collectors of heat pumps were executed in the assessed territory in latest years. Documentation was found concerning some of them only in the archive of ČGS (Czech Geological Survey) - Geofond, these boreholes are often not documented in archives.

We do not expect influence of deep bored wells or boreholes for heat pumps in the respective locality from the viewpoint of designed route of the mined tunnel. No such structures are situated in the route according to documents received from ČGS (Czech Geological Survey) - Geofond Prague.

Significant abstraction structure – the Castle Water Duct – passes in the vicinity of the designed construction. It collects shallow groundwater from the area of the Liboc Pond as well as groundwater of Cretaceous deposits of the Střešovice plane (by means of several galleries of expected length of 20 - 130 m) according to archive documents (information from the Water Right Authority of the Office of City District Prague 6, taken over from - J. Soukup, I. Koroš (2016)). The Castle Water Duct collects groundwater of first tens l/s yield overall. The Castle Water Duct is used as a source of service water. The location of Castle Water Duct and of infiltration galleries is shown in the detailed layout. **The Cretaceous collector will not be adversely influenced by the designed construction of the mined tunnel, it is necessary to ensure technical execution (unsealing) only in case of individual building structures (e.g. exhausts) leading to the surface in the area of Cretaceous plane so that the Cretaceous collector is not permanently drained towards depth.**

No deeper bored wells or boreholes for heat pumps are situated at the premises of Military Hospital in Střešovice according to the archive documents taken over (J. Soukup, I. Koroš 2016).

No excavated wells are situated at the premises of heating plant in Veleslavín according to information of the site administrator; groundwater collected by the gallery for hot water pipeline (ballast water) is used as service water here – the gallery receives groundwater collector bonded to Cretaceous sandstones that will not be influenced by the designed construction. The excavated well S14/P007707 mentioned in archive documents (Papoušek, L., 1959) is not situated here any more here presently.

6. LOGGING MEASUREMENT IN BOREHOLES J11, J14, HJ15, AND HJ16

A weak groundwater streaming was only detected in individual more permeable positions at the altitude of approximately 48 – 79 m under ground level by the logging measurement in the borehole HJ11; groundwater streaming does not occur in greater depths of the respective borehole. The borehole yield was determined as 0.012 $l.sec^{-1}$. Gradients of strata planes move in a very narrow range of inclinations in HJ11 borehole similar to HJ14 borehole, the average inclination corresponds to 43.4° value. Nor the scattering of recorded directions of gradients is not large, its average value is 160°.

A weak groundwater streaming was only detected in individual more permeable positions at the altitude of approximately 12 – 58.5 m under ground level by the logging measurement in the borehole J14. Water inflows were detected in the depth interval of the tunnel mining in the amount of approximately 80 l/day, in the maximum amount of 190 l/day. The borehole yield was determined as 0.02 l.sec^{-1}. Groundwater streaming does not occur in greater depths in the respective borehole, or groundwater is being lost through systems of waterless open fissures not filled with clay. Weathered Ordovician shales found are strongly disrupted up to the depth of 8.3 m. Positions of weakly disrupted and disrupted rock masses alternate deeper to the depth of 19.4 m. The rock mass is tectonically undisrupted or weakly disrupted from this depth up to the bore end with the exception of two tectonically disrupted positions: 29.5 – 31.1 m and 44.8 – 45.8 m. The gradients of strata planes move in a very narrow range of inclinations (approximately 45°- 55°) in PJ14 borehole, the average inclination corresponds to 43.59° value and is equivalent to J11 borehole. Nor the scattering of recorded directions of gradients is not large (135° - 165°), its average value is 155°.

A strong groundwater streaming was detected in individual more permeable positions at the altitude of approximately 5.4 – 17.7 m under ground level by the logging measurement in the borehole HJ15. The streaming occurs in quaternary deluvial sediments and in the upper weathered and loosened zone of the rock mass subbbase. We expect that especially the groundwater horizons in the environment of deluvial sediments are supplied by hidden inflows from Cretaceous sediments that are situated south of HJ15 borehole (Cretaceous sedimentary rock masses are seated discordantly at underbed rock masses of Ordovician age). Other weaker flows (inflows) were found in 12.5-20.0 m interval in the environment of weathered, (tectonically) disrupted Ordovician rock masses of Letná series of strata irregularly. The main zones of water inflows (3 pcs) are approximately 0.5-1.1 m thick. Considerable groundwater streaming does not occur more deep in the given borehole. The borehole was not passable for the measuring devices from the depth of 21.5 m; the generally low quality of the rock mass environment was the reason. It concerned strong cracking above all that caused falling irregular rock mass fragments to the borehole. From the point of view of courses of disturbances and the tectonic disturbance, HJ15 borehole can be evaluated as considerably heterogeneous with several significant disturbance zones. According to the RQD evaluation and the macroscopic description, the most significant disturbance zones were found in depths of 20-23 m, 29-30.3 m, 31-31.5 m, 32.0-32.5 m 32,95-33.5 m, 34-34.4 m, 35-35.4 m, 35.8-37.8 m, 38.4-38.8 m, 39.2-39.35 m, 42.5-42.7 m, 43.2-44.2 m, 45.1-45.40 m, 48.9-49.8 m. 50,35-50.8 m 54.6-54.8 m. Less favourable GT conditions (e. g. heavier outbursts of water) are to be expected in disturbance zones. Gradients of strata planes in HJ15 borehole correspond approximately to gradients in surrounding boreholes.

A strong groundwater streaming was detected in individual more permeable positions at the altitude of approximately 30.0 – 43.0 m under ground level by the logging measurement in the borehole HJ16. The streaming occurs at the base of Cretaceous sedimentary rock masses and in upper loosened, cracked and weathered zone of subgrade Ordovician rock masses. Weaker flows (inflows) were found at 49.5-70.0 m interval in the environment of weakly weathered, (tectonically) disrupted Ordovician rock masses of Letná series of strata irregularly. Zones of water inflow (5 pcs) are approximately 0.4-0.6 m thick. Considerable groundwater streaming does not occur more deep in the given borehole. HJ16 borehole may be evaluated as heterogeneous from the point of view of discontinuities course and tectonic disruption with several significant disturbance zones in depths of 35.84 m, 36.48 m, 42.23 m, 49.09-49.47 m, 50.84 m, 67.07 m, 69.17 m, 75.61 m, 75.92 m, 76.61 m, and 76,91 m. Furthermore, significant lacks of environment uniformity were found in depths of 37.44 m, 43.89 m, 45.51 m, 46.18-46,25 m, 53.73-53.73 m, 56.72 m, 57.67 m, 58.34 m, 69.27 m, 69.34 m, 69.48-69.59 m, 70.53 m, 70.69-70.71 m, 70.85 m, 71.02 m, 71.61 m, 72.10 m, 73.45-73.51 m, 74.12m, 74.25 m, 74.40-74,48 m. 74,82-74,85 m, and 75,24 m. Less favourable GT conditions (e. g. heavier outbursts of water) are to be expected in disturbance zones. The gradients of strata planes move within a very narrow range of inclinations (approximately 35°- 55°) in HJ16 borehole, the average inclinations corresponds to the 40.46° value. Nor the scattering of recorded directions of gradients is not large (160° - 175°), its average value is 165°.

Results of logging measurements are specified more in detail in the report on logging measurements in the annex No. 7. The actual logging measurement in boreholes J11, J14, HJ15, and HJ16 was carried out by the company Aquatest a.s. (RNDr. Svatopluk Kořalka).

7. MEASURING DYNAMIC EFFECTS IN THE BOREHOLE AT THE INSTITUTE OF PHYSICS OF THE CZECH ACADEMY OF SCIENCES

Measuring dynamic effects in the borehole near the Institute of Physics of the Czech Academy of Sciences was carried out based on requirement of the Institute of Physics of the Czech Academy of Sciences that it was possible to verify dynamic effects of the construction on the building of the Institute of Physics. This measurement was carried out as background information for assessment of the underground route course of the modernized line Prague Holešovice – Prague Veleslavín concerning vibrations in special laboratories of the Institute of Physics of the Czech Academy of Sciences. It was carried out for the project engineer of the construction, Metroprojekt a.s., by Ing. Jan Stěnička. The actual measurement of dynamic effects in the borehole near the Institute of Physics was carried out by Inset s.r.o. (Ing. Martin Čermák) and the report of this measurements included in annex 8. The measurement was executed especially for the previous route from Feb. 2019 that was situated in close proximity of the Institute of Physics of the Czech Academy of Sciences. The current route is in the distance of more than 110 m from the building of the Institute of Physics of the Czech Academy of Sciences. The report of measurement of dynamic effects is thus attached for a case of further change of the construction route and for reasons of total complexity of the report.

8. GEOTECHNICAL EVALUATION

8.1. GEOTECHNICAL SECTIONS

Longitudinal geotechnical section of the left mined Střešovice tunnel SO 06-25-01, scale 1:2 500/250, as well as selected cross sections, were elaborated based on the results of new exploration wells, exploration wells from archive surveys and facts ascertained during the field work:

- Lateral geotechnical profiles of the eastern (entrance) mined portal at the chainage of km 4.215 and 4.322, scale 1:200/200
- Lateral geotechnical profile near the Institute of Physics of the Czech Academy of Sciences at the chainage of km 5.090, scale 1:500 – variant V5
- Geotechnical profile in the place of technology object Střešovice, at chainage km 5.598, scale 1:2000/200
- Lateral geotechnical profile of the western (exit) mined portal at the chainage of km 7.320, scale 1:200/200

New and legacy boreholes are mostly located not in the axis of newly created geotechnical sections, but in its immediate proximity. These boreholes were always projected orthogonally to the section axis and the projection image of the borehole need not agree necessarily with the level of the displayed element. The actual position of the borehole especially with respect to the slope exposition of the place of actual execution of the borehole and probable course of the rocky subbase level was always taken into consideration at creating the section.

Detailed breakdown of geotechnical types is displayed in the longitudinal section in grey colour, their parameters are specified in the Table No. 14a. However, the breakdown of geotechnical types in the longitudinal section was simplified for the needs of geotechnical calculations and this breakdown also corresponds to the simplified Table No. 14b with the values of geotechnical characteristic. This table is also shown in the legend of longitudinal geotechnical section as well as in the legend of geotechnical cross sections.

The groundwater table level is always specified based on assumption of full coincidence with the level apparent in the equipped exploration HG boreholes with respect to the limited amount of data on groundwater table, but it probable course in wider vicinity is also taken into consideration. The assumption of long-term settled water table is considered in the geotechnical sections.

8.2. GEOTECHNICAL CHARACTERISTICS OF SOILS AND ROCK MASSES

Geotechnical characteristics of soils and rock masses were acquired based on interpretation of the results new field and laboratory tests as well as of very large set of archive measurements within the geotechnical investigation for modernization of the line Prague Výstaviště (Exhibition Ground) – Prague Veleslavín. Values of geotechnical parameters of materials of similar structural and textural nature as well as stratigraphic categorisation from wider territory of interest were included to the respective selection (the whole Great Prague in case of some rocky stone masses practically). Recommended values of geotechnical characteristics of individual types of soils/rock masses are summarized in following overviews in tables 14 to 16. They are of the nature of local standard subsoil characteristics (with the exception of the calculated bearing capacity) here. They must be reduced through coefficients of reliability according to limit conditions in the static assessment.

They are considered as quasihomogeneous in case of **rocky stone masses** of respective geotechnical characteristics, i.e. that gradual change properties due to gradually decreasing degree of weathering and due to blistering towards the depth is respected, however, neglecting further dissipation of geotechnical parameters owing to the variable degree of diagenetic lihificatation or presence of weakening or solidifying positions etc., the considering of which would result in partial overlapping of values of adjacent layers. Thus, the summaries specify always one value of weight, deformation and strength characteristics for each horizon characterized by the degree of weathering W1 to W5.

Tables 14 to 16 contain **following characteristics** for the reached horizons:

Basic physical:

- volume weight in natural bedding γ_n [kN . m^{-3}]
- coefficient of filtration k_f [m . s^{-1}]

Deformation characteristics:

- deformation modulus E_{def} [MPa]
- elastic modulus E [MPa]
- Poisson's ratio ν [MPa]

Strength characteristics:

- effective cohesion c_{ef} [kPa]
- effective angle of internal friction (or strength angle) ϕ_{ef} [°]

<u>Standard categorisation:</u>
- ČSN P 73 1005 “Engineering-Geological Survey”, 2016 (preliminary standard)
- ČSN 73 6133: “Design and Execution of Earth Body of Underground Roads” - symbol or categorisation and also workability of soils and rock masses, suitability for embankments and active zones of road underbed.
- ČSN 73 1001 “Subsoil under Spread Footing” (validity expired in 2010) tabular bearing capacity Rdt
- ČSN 73 1002 “Pile Foundations“ - (validity expired in 2010) – vertical tabular vertical bearing capacity $U_{v,tab}$ for bored piles **diameter d = 1.0 m** and **fixing lengths** for respective horizon **lf = 1.5 m**.
- Price list 800-2 „Classification of rock masses for drilling piles“.

An interesting and for the construction in question very adverse circumstance ensues for **Letná and Dobrotivian series of strata** from comparison of the latter specified group (Paleozoic): ***Deformation and strength characteristics*** are ***substantially lower*** compared to central part of Prague (especially the part adjacent to Vltava river channel). This is caused by the altitudinal position here – it is higher by approximately 150 m compared to the Vltava riverbank.

Note: *This statement is confirmed by newly ascertained characteristics of* ***Libeň series of strata*** *that is situated in the area of eastern beginning of the structure – in the low altitudinal position still corresponding to the central part of the city adjacent to Vltava river. Detected properties are practically the same (or even somewhat better) here than determined by us in the 1990s at the survey for car tunnel Mrázovka.*

Tab. 8.2.a: Summary of recommended geotechnical characteristic of soils of capping masses

stratigraphic formation and genetic complex		geotype / symbol of the strata and degree of weathering		volume weight in natural bedding γ [kN.m-3]	filtration coefficient k_f [m.s-1]	deformation characteristics			shear strength 1)		symbol acc. to ČSN P 73 1005, ČSN 73 6133	tabular bearing capacity R_{dt} [kPa]	tabular vertical bearing capacity pile $U_{v,tab}$ [kN] 2)	workability acc. to ČSN 73 6133 / 73 3050	borability of piles acc. to price list 800-2	suitability for embankments / *of active zone* acc. to ČSN 73 6133 3)
						deformation modulus E_{def} [MPa]	elastic modulus E [MPa]	Poisson's ratio ν [1]	cohesion c_{ef} [kPa]	angle of internal friction ϕ_{ef} [°]						
QUARTERNARY sediment	made-grounds	**AN**	**undifferentiated**	18.0	10^{-6}	2-10	10	0.35-0.30	5	26	**(Y)**	*	*	I / 3	I (III)	CS to UN CS to UN/
Quarternary sediment - Pleistocene	eolian and eolian-deluvial sediments	**Eol1**	**loam or even clay with low or even medium plasticity**	20.0	10^{-8}	5	10	0.40	12	18	**MI, CI**	100	630	I / 2 - 3	I	CS / UN
	deluvial sediments with chips of Cretaceous and Ordovician rock masses	**Dl2**	**loam or even sandy clay**	18.5	10^{-8}	10	20	0.35	14	24	**MS, CS**	175	630	I / 2 - 3	I	CS / *CS*
		Dl3	**loam or even clay with medium plasticity**	20.5	10^{-8}	6	12	0.40	15	19	**MI, CI**	150	630	I / 3 - 4	I	CS / *UN*
		Dl4	**loamy or even clayish gravel**	19.5	10^{-7}	50	100	0.30	5	32	**GM, GC**	300	630	I / 4 - 5	I - II	CS / *CS*
	deluvio-fluvial sediments	**Dfl1**	**predominantly loamy or even clayish sand.**	18.5	10^{-7}	12	25	0.35	6	28	**SM, SC**	225	480	I / 3	I	CS / *CS*

stratigraphic formation and genetic complex	geotype / symbol of the strata and degree of weathering		volume weight in natural bedding γ [kN.m-3]	filtration coefficient k_f [m.s-1]	deformation characteristics: deformation modulus E_{def} [MPa]	deformation characteristics: elastic modulus E [MPa]	deformation characteristics: Poisson's ratio ν [1]	shear strength [1)]: cohesion c_{ef} [kPa]	shear strength [1)]: angle of internal friction ϕ_{ef} [°]	symbol acc. to ČSN P 73 1005, ČSN 73 6133	tabular bearing capacity R_{dt} [kPa]	tabular vertical bearing capacity pile $U_{v,tab}$ [kN] [2)]	workability acc. to ČSN 73 6133 / 73 3050	borability of piles acc. to price list 800-2	suitability for embankments / *of active zone* acc. to ČSN 73 6133 [3)]
	Dfl2	**loam or even sandy clay**	19.0	10^{-7}	12	25	0.35	20	25	**MS, CS**	175	630	I / 2 - 3	I	CS / *CS*
	Dfl3	**loam or even clay with medium plasticity**	21.0	10^{-8}	8	15	0.40	16	20	**MI, CI**	150	630	I / 3	I	CS / *UN*
fluvial sediments	**Fl1**	**sand with admixture of fine grain soils**	18.0	10^{-5}	25	50	0.30	0	32	**S-F**	275	480	I / 3 - 4	I	SU / *CS*
fluvial sediments	**Fl2**	**predominantly loamy or even clayish sand**	19.0	10^{-7}	15	30	0.33	5	29	**SM, SC**	225	480	I / 3	I	CS / *CS*
fluvial sediments	**Fl3**	**gravel with admixture of fine grain soil**	19.0	10^{-5}	90	180	0.25	0	35	**G-F**	275	480	I / 3	I	SU / *CS*

Notes:

[2)] for the pile diameter d = 1.0 m and fixing length lf = 1.5 m according to the original ČSN 73 1002

[3)] NU ... not usable, SU ... suitable, CS ... conditionally suitable, UN ... unsuitable (for direct usage without treatment), HRS or SRS... to be used for embankments from hard or soft rocky stone masses

***Note:** All specified strength, deformation and weight parameters are of the nature of local standard subsoil characteristic with the exception of the calculated bearing capacity*

Tab. 8.2.b: Summary of recommended geotechnical characteristics of rock masses of rockbed -

stratigraphic formation and genetic complex		geotype / symbol of the strata and degree of weathering		volume weight in natural bedding γ [$kN.m^{-3}$]	filtration coefficient k_f [$m.s^{-1}$]	deformation characteristics			shear strength 1)		compression strength σc (tensile strength σt) [MPa]	categorization according to ČSN P 73 1005 ČSN 73 6133	tabular bearing capacity R_{dt} [kPa]	tabular vertical bearing capacity pile $U_{v,tab}$ [kN] 2)	workability according to ČSN 73 6133 / 73 3050	borability of piles acc. to price list 800-2	Suitability for embankments /active zones according to ČSN 73 6133 3)
						deformation modulus E_{def} [MPa]	elastic modulus E [MPa]	Poisson's ratio ν [1]	cohesion c_{ef} [kPa]	angle of internal friction ϕ_{ef} [°]							
MESOZOIC, upper chalk, turon, Bílá Hora series of strata	**sandy marlstones - sandy marls**	**KT**	**weakly weathered or even sound**	22.0	10^{-8}	400	800	0.25	150	33	**15-40 (1.5)**	**R3**	700	2500	III/5	IV	HRS
MESOZOIC, upper chalk, cenoman, series of strata of Peruc-Korycany	**fine grain quartz glauconitic sandstones**	**KCp**	**sound**	20.0	10^{-7}	45	90	0.30	30	30	**2-5 (-)**	**R5, R4, R5 locally**	325	1250	I-II/ 4	II-III	CS / CS
	claystones or even siltstones	**KCj**	**sound**	21.0	10^{-9}	20	30	0.40	60	22	**1-3 (-)**	**R6, R5**	250	1200	I/4	II	UN / UN

1) applicable in the general direction towards discontinuity areas *2) for pile diameter d = 1.0 m and fixing length l_f = 1.5 m according to original ČSN 73 1002*

3) SU ... suitable, CS ... conditionally suitable, UN ... unsuitable (for direct usage without treatment), HRS or SRS ... to be used for embankments from hard or soft rocky stone *masses*

Note: *All specified strength, deformation and weight parameters are of the nature of local standard subsoil characteristic with the exception of the calculated bearing capacity*

Cretaceous rock masses will not be reached during the execution of the CENTRE variant.

Tab. 8.2.c: Summary of recommended geotechnical characteristics of rocky stone masses - Paleozoic

stratigraphic formation and genetic complex		geotype / symbol of the strata and degree of weathering		volume weight in natural bedding γ [kN.m^{-3}]	filtration coefficient k_f [m.s^{-1}]	deformation characteristics			shear strength 1)		compression strength σ c (tensile strength σ t) [MPa]	categorization according to ČSN P 73 1005 ČSN 73 6133	tabular bearing capacity R_{dt} [kPa]	tabular vertical bearing capacity pile $U_{v,tab}$ [kN] 2)	workability according to ČSN 73 6133 / 73 3050	borability of piles acc. to price list 800-2	Suitability for embankments /active zones according to ČSN 73 6133 3)
						deformation modulus E_{def} [MPa]	elastic modulus E [MPa]	Poisson's ratio ν [1]	cohesion c_{ef} [kPa]	angle of internal friction ϕ_{ef} [°]							
PALEOZOIC Ordovician, Letná series of strata	silty shales and greywacke sandstones	**Ltn/W5-W4**	**fully or even heavily weathered**	18.5	10^{-8}- 10^{-6}	15	25	0.38	15	25	**<3.0 (-)**	**R6, R5/R6**	150	850	I / 4	I	CS / *CS*
		Ltn/W3	**weathered**	22.0	10^{-8}- 10^{-9}	60	150	0.35	30	28	**3-6 (-)**	**R5**	300	1000	I / 4	II	SRS
		Ltn/W2	**weakly weathered**	25.0	10^{-9}	150	300	0.30	100	33	**6-12 (0.5)**	**R4**	400	1250	II / 5	III	SRS
		Ltn/W1	**sound**	25.5	10^{-9}	500	1000	0.25	250	36	**12-25 (1.4)**	**R3**	800	2500	III / 5	III	SRS
		Ltn/TEKT	**tectonically disrupted**	24.0	10^{-9}	60	120	0.30	60	28	**3-12 (0.3)**	**R5, R4**	200	1250	I / 4	II	CS / CS
Ordovician, Dobrotivian series	**silty shales**	**Dbr/W5-W4**	**fully or even heavily weathered**	20.5	10^{-7}	8	20	0.40	20	20	**<1.5 (-)**	**R6**	150	800	I / 4	I	CS / *CS*

stratigraphic formation and genetic complex	geotype / symbol of the strata and degree of weathering		volume weight in natural bedding γ [kN.m^{-3}]	filtration coefficient k_f [m.s^{-1}]	deformation characteristics			shear strength [1]		compression strength σ c (tensile strength σ t) [MPa]	categorization according to ČSN P 73 1005 ČSN 73 6133	tabular bearing capacity R_{dt} [kPa]	tabular vertical bearing capacity pile $U_{v, tab}$ [kN] [2]	workability according to ČSN 73 6133 / 73 3050	borability of piles acc. to price list 800-2	Suitability for embankments /active zones according to ČSN 73 6133 [3]
					deformation modulus E_{def} [MPa]	elastic modulus E [MPa]	Poisson's ratio ν [1]	cohesion c_{ef} [kPa]	angle of internal friction ϕ_{ef} [°]							
	Dbr/W3	**slightly weathered**	22.0	10^{-7}-10^{-8}	30	60	0.35	25	25	**1.5-4 (-)**	**R5**	200	1000	I / 4	II	SRS
	Dbr/W2	**weakly weathered**	25.0	10^{-8}	80	250	0.30	60	30	**4-8 (0.4)**	**R4**	250	1250	II / 5	III	SRS
	Dbr/W1	**sound**	26.0	10^{-9}	200	400	0.25	150	33	**8-15 (1.2)**	**R4/R3**	400	1400	II / 5	III	SRS
	Dbr/TEKT	**tectonically disrupted**	24.5	10^{-7}	40	100	0.35	50	26	**2-8 (0.3)**	**R5, R4**	200	1250	I / 4	II	CS / CS

[1] *applicable in the general direction towards discontinuity areas* [2] *for pile diameter d = 1.0 m and fixing length l_f = 1.5 m according to original ČSN 73 1002*

[3] *SU ... suitable, CS ... conditionally suitable, UN ... unsuitable (for direct usage without treatment), HRS or SRS ... to be used for embankments from hard or soft rocky stone masses*

Note: *All specified strength, deformation and weight parameters are of the nature of local standard subsoil characteristic with the exception of the calculated bearing capacity*

8.2.1. Workability and borability of soils and rock masses

Categorisation according to the currently valid ČSN 73 6133 and ČSN P 73 1005, distinguishing three workability classes for construction of ground roads on the one hand, and the still deep-rooted classification according to the original, already invalid ČSN 73 3050, on the other hand, is used at the classification of rock masses and soils from the viewpoint of workability and borability. Categorisation of borability for piles according to the Catalogue of Description and Guidance Prices of Construction Works 800-2 and the prevailing symbol of categorisation of soils and rock masses according to ČSN 73 6133 or ČSN P 73 1005 are specified, too. We specify all categorisations also in the summary of geotechnical characteristic in the Tables No. 14 to 16 of the preceding chapter and collectively, for the sake of lucidity, also at this place. Local more precise specification of the overall general categorisation of individual geotypes was often possible from the viewpoint of workability and borability in a partial way according to individual structures or route sections based on extensive exploration works and results of laboratory tests.

The categorisation was elaborated based on geological documentation of archive as well as new boreholes, especially on the description of macroscopic signs of rock masses, taking into consideration the results of laboratory tests.

Table 8.2.1.a : Categorisation of rock masses according to workability and borability classes

rock mass	geotype	Symbol / class according to ČSN P 73 1005 / 73 6133	workability according to ČSN 73 6133/ex 73 3050		borability class according to VC 800-2
Quarternary nappe					
Recent - made-grounds					
loamy and stone-sandy made-grounds, predominantly solid	AN	Y	I	3	I (loc. II)
Pleistocene					
eolian and eolian-diluvial sediments	Eol	MI, CI, MS, CS	I	2	I.
diluvial sediments with chips of Cretaceous rock masses	Dl2, Dl4	MI, CI, GC, GC	I	3-4	I.
diluviofluvial sediments	Dfl1	CS, SC, CI, MI	I	3	I.
fluvial sediments	Fl1	SC, S-F	I	3	I.
fluvial sediments	Fl3	G-F, GP	I	3-4	I - II
Rockbed – Mesozoic, upper chalk					
TURON - Bílá hora series of strata: fine sandy marlstones (sandy marls)					
weakly weathered or even sound	KT	R3	III	5	III-IV.
CENOMAN – Peruc-Korycany series of strata					
fine grain quartz sandstones - sound	KCp / W1	R5	I	5	III

rock mass	geotype	Symbol / class according to ČSN P 73 1005 / 73 6133	workability according to ČSN 73 6133/ex 73 3050		borability class according to VC 800-2
claystones or even siltstones - sound	KCj / W1	R6	I	4	II.
Paleozoic					
ORDOVICIAN - Letná series of strata: silty shales and greywacke sandstones					
fully or even heavily weathered	Ltn / W5-W4	R6	I	4	I.
slightly weathered	Ltn / W3	R5	I	4	II.
weakly weathered	Ltn / W2	R4	II	5	III
sound	Ltn / W1	R3	III	5	III-IV
tectonically disrupted	Ltn / TEKT	R6	I	4	II.
ORDOVICIAN - Dobrotivian series of strata: silty shales					
fully or even heavily weathered	Dbr / W5-W4	R6	I	4	I.
slightly weathered	Dbr / W3	R5	I	4	II.
weakly weathered	Dbr / W2	R4	II	5	III
sound	Dbr / W1	R4	III	5	III
tectonically disrupted	Dbr / TEKT	R5	I	4	II.

Table 8.2.1.b – conversion of workability classes

ČSN 73 6133 Valid from 02/2010	**ČSN 73 3050** Validity expired in 03/2010
Class I	Extraction carried out by common excavation machinery (bulldozers, diggers, excavations carried out manually). These are class 1 to 3, 4 a), b), c), f) according to ČSN 73 3050
Class II	Special disintegrating machinery (rippers, rock shovels, hammers) must be used for the extraction and disintegration of rock masses. These are classes 4 d), e), 5th class according to ČSN 73 3050
Class III	The heaviest rippers, heaviest hydraulic hammers or blasting operations must be used for disintegration. It is the class 6 and 7 according to ČSN 73 3050

8.3. TECHNOLOGICAL EVALUATION OF SOILS AND ROCK MASSES

This chapter deals with „Usability of Soils And Rock Masses of Mined rock for Exposed Embankment Bodies“ above all. Furthermore, it is also reasonable to summarize very briefly the issues of abrasiveness of rocky stone masses (in detail see Chapter 4.3.7)

EXTREMELY HIGH ABRASIVENNES (or CAI of 4.42 value) was ascertained only in case of Letná series of strata, of monotonous development, W 1 – sound lamina of fine grain quartzites, R 2. However, these are secondary insertions only in the shale massif. **MEDIUM ABRASIVENNES** (or CAI of 1,03-1,39 value) was ascertained in case of Letná series of strata, of monotonous development, W 1 – transition between shales and quartz sandstones, R 3. In case of all other 6 samples, average values of CAI were ascertained in narrow interval of 0.66–0.97 with identical **LOW ABRASIVENNES** classification.

8.3.1. Usability of soils and rock masses from the muck in exposed embankment bodies

Considerable volume of muck will originate from the mined double-rail section (length of approximately 6.212 km) during the construction of the modernization of Prague railway line from the Exhibition Grounds to Veleslavín and it is, of course, important that this muck is not destined for landfill, but is used in economic way. However, this is a problem, since the quality of its major part will be very bad. For example, the possibility to use even its part for active zone of roadway underbeds cannot be expected within road constructing.

The coefficient of rock mass loosening may be considered in the range of 1.25 - 1.5 depending on the method of rock mass disintegration.

Nature of muck :

- Natural aggregate resulting from extraction and eventual further modification by crushing without change of the mineral and chemical composition,
- extracted aggregate modified by extraction and eventual subsequent crushing to :
  - small aggregate containing fraction in the range 2 - 22 mm
  - rough aggregate with grain size over 22 mm

In the following Table 18, the muck quality is categorized with relation to its occurrence in respective sections (this will be specified more precisely in the detailed survey):

Tab. No. 18 Categorisation of muck based on suitability to be used in embankments according to ČSN 73 6133

cut-and-cover section					muck		
number	beginning [km]	end [km]	length [km]	length [%]	type of muck	prevailing symbol - class according to according to	suitability for exposed embankment
1	4.215	4.590	0.375	11.65	Dfl1-deluvioflluvial sediments	CS,SC	CS
2	4.590	4.665	0.075	2.33	Ltn/W4-3 – of Letná, weathered	R5	SRS
	4.665	4.730	0.065	2.02	Ltn/W2 – of Letná, weakly weathered	R4	SRS
3	4.730	4.825	0.095	2.95	Ltn/W1 - of Letná, sound	R3	SRS
4	4.825	4.955	0.130	4.04	Ltn/TEKT - of Letná, disrupted	R4, R5	CS
5	4.955	6.035	1.080	33.55	Ltn/W1 - of Letná, sound	R3	SRS

6	6.035	6.170	0.135	4.19	Ltn/TEKT - of Letná, disrupted	R4, R5	CS
7	6.170	6.680	0.510	15.84	Ltn/W1 - of Letná, sound	R3	SRS
8	6.680	6.750	0.070	2.17	Dbr/TEKT – Dobrotivian, disrupted	R4, R5	CS
9	6.750	7.230	0.480	14.91	Dbr/W1 – Dobrotivian, sound	R4	SRS
10	7.230	7.322	0.092	2.85	Dbr/W2 – Dobrotivian, weakly weathered	R4, R5	CS

A) Soils of capping masses will be probably found only at the route beginning route near the eastern entrance portal, namely in the 1st section - chainage of approximately 4.215 to 4.590 km. They will belong to deluviofluvial sediments of type Dfl2 and Dfl3 in development CS or even SC (clay sandy or even sand clayish) and also in development CI (medium plastic clay, with chips of rock masses). Road standard ČSN 73 6133 „Design and Execution of Earth Body of Ground Roads“ from 2010 in the Table 1, classifies them as Dfl2 type, conditionally usable for embankments and active zone of underbeds. The Dfl3 type is then classified as conditionally suitable for embankments and as unsuitable to be used in active zones of roads. The conditionality of the sediments consist in suitable humidity of soils (near to optimum for compacting) and also in eventual application of improving additions (for example improving by lime). Danger of soil over-dampening is considerable here at the tunnelling under the groundwater table. Unsuitable soils must be always improved by suitable bonding agents according to the above mentioned standard prior to using.

Palaeozoic rocky (or semi-rocky) stone Ordovician masses of Letná and Dobrotivian series of strata will occur exclusively in further sections in the altitudinal level of the tunnel tube. Sound rock masses will be absolutely prevailing as regards weathering. They will be weakly weathered in the parts close to portals only (in case of the western Veleslavín portal, also heavily and slightly weathered).

At this application and assessment of data from the Table 9, the sections with approximately equal quality are merged for the sake of simplification and shortening. The processing procedure is selected from the worst rock masses to the relatively best ones.

B) Section with R5 rock masses – with very low strength:
It concerns the 9th and partly also the 2nd and 4th, 6th, 8th section of approximately 432 length, in weathered silty shales of Dobrotivian and Letná series of strata. It will be crushed material from soft shale with clayish filling, i.e. having the nature of soil sensitive to water content. Over-dampening is very probable here again and that is why we recommend destination for quite undemanding earth bodies (but still compacted), for example subbases under grass surfaces or embankments of artificial terrain walls.

C) Sections with R4 rock masses – with low strength:
It concerns partly the sections 2. and 6., then also sections 8. and 9.with already important representation, approximately 650 m long. Smaller part of the material will be from the weakly weathered beginning part of Letná series of strata and the larger part will be from the end part in sandy shales of Dobrotivian series of strata. Furthermore, it will concern material from tectonically disrupted areas. It is a semi-rocky stone mass classified as soft loose material (namely close to the lower limit of allowability). It is evaluated as conditionally suitable for eventual using in exposed

embankments. A detailed geotechnical investigation must be focused on more precise specification of these conditions.

D) Sections with R3 rock masses – with medium strength:
It concerns the sections 3., 5. and 7., with substantial representation of the rock mass three. R3, of approximately 1685 m length. The material is from the sound Letná series of strata. This rock mass is still classified as soft loose material (but close to the upper boundary with hard loose material). It is again evaluated as conditionally suitable and to be used in exposed embankments and the respective conditions will be specified more precisely in a subsequent detailed survey.

Lower-Palaeozoic sedimentary rock masses of Ordovician age will be extracted at mining the tunnel. This concern specifically the Letná and Dobrotivian series of strata. The respective series of strata are formed by siltstones, shales, greywackes predominantly, as well by quartzites locally. Shales and siltstones of the Dobrotivian series of strata belong among the diagenetically less lihificated ones. Unweathered and weakly weathered rock masses are temporarily resistant against weathering processes. Their decomposition to small chips and splinters with clay-silty gap filling substance occurs at longer exposure to climatic and weather influences. Clay-silty, dangerously frost susceptible soils with admixture of soft splinters from the substratum are the final product then. The Letná series of strata with higher share of sandstones, quartzites and greywacke belongs among the most resistant ones against weathering processes. Unweathered and weakly weathered rock mass are predominantly resistant against weathering processes. Decomposition of greywackes to small chips and splinters occur at longer exposure to climatic and weather influences. Gravel-loamy, fine sandy soils are the final product then. Rock masses must be defragmented to fractions of suitable granularity prior to re-using. Quartzites belong among the most resistant rock masses in the respective territory. The rock masses decompose to irregular stones or even blocks. Quartzites are stable in volume and mechanically resistant. Rock masses must be defragmented to fractions of suitable granularity prior to re-using.

We expect fully crushed rock masses of the nature of clay-silt-gravel soils in heavily tectonically disrupted places, even clays with chips of rock masses locally. Tectonically disrupted rock masses are predominantly dangerous as regards frost susceptibility; they are unstable and prone to become slushy in case of higher share clay-silty fraction. Surface protection against erosion and freezing will be necessary in case of using for embankment bodies.

It will be necessary to verify the rock mass properties by operating survey at the beginning of the tunnel mining (see Cl. 7.8. of ČSN 73 6133).

8.4. ALTITUDINAL COURSE OF STŘEŠOVICE MINED TUNNELS VARIANT CENTRE

The altitudinal course of the mined tunnels is optimal with respect both to the thickness of the rock cover, and to the thickness of overburden as regards the built-up area Recessing the vertical alignment of the tunnels at the eastern entrance portal into the rockbed is not realistic, namely for reasons of the altitudinal joint on the cut-and-cover part of the construction.

8.5. HORIZONTAL ALIGNMENT OF THE ROUTE OF STŘEŠOVICE MINED TUNNELS - VARIANT CENTRE

Horizontal alignment of the route is from the viewpoint of engineering-geological conditions different from the previous phase of exploration works in 02/2019, namely in the initial route section above all. The new variant completely by-passes the Institute of Physics of the Czech Academy of Sciences, as well as the Ořechovka villa district, where complicated negotiations concerning the construction with the property owners was expected. The clay-silty shales of the Libeň series of strata will not be reached any more within the new variant. We expect only the occurrence of partly tectonically disrupted silty shales with minor positions of greywacke sandstones of the Letná series of strata in the new variant of the initial construction section. Rock masses of the Letná series of strata will be reached approximately in 75 % of the tunnel route. Then, we expect reaching the shales of Dobrotivian series of strata from the chainage at km approximately 6.750 – approximately 25 % of the construction.

8.6. EASTERN MINED EXIT PORTAL

The eastern mined entrance portal continuously joins the cut-and-cover Dejvice tunnel.

The building pit will be excavated only in quarternary sediments for this portal, specifically in Pleistocene deluviofluvial sediments. Reaching eolian/eolian-deluvial sediments (loesses and loess-like loams) can neither be ruled out locally. The tunnel bottom lining will irregularly protrude to fluvial sediments of the higher terrace degree of Vltava river – Dejvice terrace. Continuous groundwater table is assumed approximately 3-4 m below the building pit in sandy sediments of the relict of Dejvice terrace of Vltava river. Its protruding above the level of the tunnel bottom lining is to be expected in the vicinity of the chainage at km 4.500. However, little strong inflows of small yield from the small suspended aquifers tied to discontinuous sandy positions in deluviofluvial sediments are not ruled out then. Rockbed (silty shales with sandstone positions – Letná series of strata) is assumed under the building pit in question.

We recommend to secure the building pit and the walls of the mined portal by means of special method of foundation engineering – diaphragm walls. If these structures are executed down to the surface of rockbed, it is necessary to take into account the possible influence of groundwater streaming – its swelling – forming so called dam. That is why it is necessary take into account such design solution that makes possible streaming below the underground walls.

8.7. WESTERN MINED EXIT PORTAL

The western mined exit portal continuously joins the cut-and-cover Veleslavín tunnel.

The building pit for this portal will be excavated predominantly in silty or even clay-silty shales of the Dobrotivian series of strata that are heavily tectonically disrupted to the depth of approximately 20 m. This tectonic disruption of the rock massif weakens the wall of the mined portal. Continuous groundwater table is assumed in the weathered rockbed, but it is dependent probably on overflows from the aquifer in Cretaceous sandstones. This also indicates the factuality of the information on intermittent waterlogging of this territory.

We recommend to secure the building pit and the walls of the mined portal by means of special method of foundation engineering – e.g. anchored pile walls. Here, it is also necessary to take into account the possible influence of groundwater streaming – its swelling – forming so called dam. That is why it is necessary take into account such design solution that makes possible streaming below the underground construction.

8.8. MINING STŘEŠOVICE TUNNELS – VARIANT CENTRE

This evaluation tunnelling conditions is based on results of the geotechnical investigation. Longitudinal geotechnical section of the left mined Střešovice tunnel SO 06-25-01 (new Variant CENTRE) was elaborated based on the geological description of new survey boreholes within the above mentioned survey where among others individual geotechnical types of rock masses were defined based on lithological description and executed laboratory and field tests and probable course of groundwater table was compiled as reached in the exploration wells.

Tab. No. 10 Breakdown of the Střešovice mined tunnel to building structures according to the project design documentation.

Building structure of mined tunnel	Name	Chainage
SO 06-25-01	Mined left tunnel Střešovice	km 4.215-7.322 (length of 3.107 km)
SO 06-25-02	Mined right tunnel Střešovice	km 4.200-7.305 (length of 3.105 km)
SO 06-25-03	Cross passages Střešovice	see the layout drawing
SO 06-25-04	Střešovice technological	km 5.598

We consider geological conditions in the route of both mined tunnels as complicated, because the vertical alignment tunnel mining leads in the route beginning (at the eastern portal) in soil environment of deluviofluvial and deluvial sediments with overburden of eolian sediments, then it continues through rocky massif that is markedly tectonically disrupted with the development of tectonic disturbances or even disturbance zones in Ordovician rock masses of Letná and Dobrotivian series of strata here and there. A disturbance zone was verified by drilling works in the area of the mined western portal. Moreover, the prevailing part of the mined route is situated under the groundwater table

Mined constructions must be classified in 3rd geotechnical category in terms of ČSN EN 1997-1, to which buildings belong with demanding structure in complicated geological conditions and with consideration of geotechnical risks of the construction. We consider the structure of Střešovice mined tunnel to be demanding, as it is - among others - underground work below built-up area and technical infrastructure.

So called quasihomogeneous units were determined based on the above mentioned geotechnical section for individual tunnelling sections according to requirements for engineering-geological documentation of underground construction, Section 17 of the Decree of Czech Mining Authority No. 55/1996 Coll. as amended according to the Decree 265/2012 Coll. dated 1 September 2012 that include sections of tunnelling of similar properties, with engineering-geological properties of rock massif and bedding of rock masses with respect to the face and line of excavation, especially from the viewpoint of stratification, deformation and strength properties of rock masses, quality and orientation of strata planes, cohesion, danger of withdrawing and spalling, permeability, borability and suitability for anchoring. Furthermore, they include information on the course of geological disturbances, on assumed places with increased pressures of rock mass, on the course of capping masses, on the weathering depth and on the groundwater table, on height of overall and rock mass environment, data on location of weakened zones in the rock massif with markedly lower structural strength in cases of underground construction shallow situated under the surface, on places of water seepage and on overall hydrogeological conditions. These quasihomogeneous units are characterized by recommended parameters of the rock massif for calculating the rock mass pressure, for dimensioning the reinforcement and for determining the method of disintegration. This engineering-geological evaluation contains also data on the surroundings of the underground construction to the distance of their possible affecting according to the above quoted decree, i.e. information on engineering-geological conditions, on the nature of overground built-up area, on ground surface and underground services within the range of possible affecting by the underground construction, their condition and resistivity

8.9. DISTRIBUTION OF TUNNELLING INTO QUASIHOMOGENEOUS UNITS

The whole route of the Střešovice mined tunnel was divided into 10 quasi-homogeneous units in total. Each unit is delimited by the chainage range.

Tab. No. 8.9.a: Rozdělení trasy levého tunelu (variant CENTRE) do kvazihomogenních celků

Quasi-homogeneous unit										
No.	1	2	3	4	5	6	7	8	9	10
Chainage of the left tunnel (rail 1) variant CENTRE	Km 4.215-4.590	Km 4.590-4.730	Km 4.730-4.825	Km 4.825-4.955	Km 4.955-6.035	Km 6.035-6.170	Km 6.170-6.680	Km 6.680-6.770	Km 6.770-7.230	Km 7.230-7.322
EG description	DFL sediment, V overburden EO sediment, in bottom lining irregular occurrence of FI sediment, at the end tunnelling under the level of groundwater	Letná series of strata weathered to weakly weathered, tunnelling under the groundwater table	Letná series of strata, sound, tunnelling under groundwater table	Letná series of strata, tectonically disrupted, tunnelling under groundwater table	Letná series of strata, sound, tunnelling under groundwater table	Letná series of strata, tectonically disrupted, tunnelling under groundwater table	Letná series of strata. sound, with overburden of Cretaceous Sediments, rock masses, tunnelling under the groundwater	Dobrotivian series of strata, sound, with overburden of Cretaceous sediments, tectonically disrupted, tunnelling under the groundwater table	Dobrotivian series of strata, sound, tunnelling under the groundwater table,	Dobrotivian series of strata, weathered, tunnelling under groundwater table

Quasi-homogeneous units were determined based on the geological section for individual tunnelling sections under Section 17 of the Decree of Czech Mining Authority No. 55/1996 Coll. as amended by Decree 265/2012 Coll. of 1 September 2012 that include sections of tunnelling of similar properties, with engineering-geological properties of rock massif and bedding of rock masses with respect to the face and line of excavation.

Individual quasi-homogeneous units are classified according to the extent of the number of points according to tunnel builders' classifications QTS (Tesař) and RMR (Bienawski). It is categorized into following technological NATM classes regardless to the tunnelling method of the respective section based on these classifications. The summary of quasihomogeneous units with guidance categorisation according to NATM classes and excavatability degrees for conventional tunnelling is included in the able No. 8.9.b.

Tab. No. 8.9.b: Guidance categorisation of the rock massif according to NATM classes for mining the Střešovice tunnels

General information on excavation						Geotechnical types and conditions of tunnelling						Classification	
Tunnelling	Chainage of the left tunnel	Width of	Height of overburden/rock cover/groundwater table (m)	NATM class for the given width (QTS)	Degree of excavatability	Geotype	Share of the excavation	RQD	Water inflow	General HG conditions	Orientation of fissures to the construction	QTS	RMR

									%								
	km	m	from	to					from	to	l/min	min.	max.	min	max	min	max
Quasihomogeneous unit 1	4.215-4.590	9.5	12.0	33.0	5b	III	Dfl2	30	-	-	8	damp	-	-	-	-	-
			-	-			Dfl3	65	-	-		damp					
			-	-			Fl2	5	-	-		wet					
Quasihomogeneous unit 2	4.590-4.730	9.5	33.0	29.0	5a	II	Ltn/W5-W4	15	0	5	15	draining	very adverse	30	35	16	25
			0	23.7			Ltn/W3	40	0	40		inflow					
			0	16.5			Ltn/W2	45	20	90		draining					
Quasihomogeneous unit	4.730-4.825	9.5	38.9	39.5	4	I	Ltn/W1	100	59	100	12	wet	very adverse	39	48	28	41
			26.7	31.4													
			16.4	21.8													
Quasihomogeneous unit 4	4.825-4.995	9.5	40.0	44.7	5a (35% in tectonic disturbances 4 (65%)	II (35%) I (65%)	Ltn/W1	65	60	90	10 to 145	wet	very adverse	31	43	21	34
			34.7	42.2			Ltn/TEKT	35	0	10		inflow					
			27.6	34.6													
Quasihomogeneous unit 5	4.995-6.035	9.5	42.1	45.0	4	I	Ltn/W1	100	60	90	85	damp	very adverse	39	49	32	44
			31.4	42.3													
			34.5	34.7													
Quasihomogeneous unit 6	6.035-6.170	9.5	45.4	46.1	5a (40 % in tectonic disturbances 4 (60%)	II (40%) I (60%)	Ltn/W1	60	30	89	15 to 130	wet	very adverse	30	41	18	30
			42.3	43.4			Ltn/TEKT	40	0	20		inflow					
			37.4	38.4													
Quasihomogeneous unit 7	6.170-6.680	9.5	45.3	63.2	4	I	Ltn/W1	100	47	93	60	damp	very adverse	40	50	38	46
			43.3	62.1													
			37.5	43.2													
Quasihomogeneous unit 8	6.680-6.770	9.5	63.2	67.1	5a (40% in tectonic disturbances 4 (60%)	II (40%) I (60%)	Dbr/W1	60	25	50	55 to 170	damp	very adverse	30	38	18	28
			62.3	65.8			Dbr/TEKT	40	0	10		inflow	very adverse				
			40.0	43.7													
Quasi-homogeneous	6.770-7.230	9.5	22.1	68.2	4	I	Dbrb/W1	100	40	90	25	damp	very adverse	38	47	34	41
			20.1	66.8													
			16.4	40.0													
Quasihomogeneous unit 10	7.230-7.322	9.5	13.5	22.1	5a	II	Dbr/W2	75	40	70	10 to 125	draining	very adverse	34	40	22	32
			11.6	20.1			Dbr/TEKT	25	0	10		inflow	very adverse				
			9.9	16.4													

8.9.1 Quasihomogeneous unit 1

This quasi-homogeneous unit was divided at the chainage of km 4.215-4.590. It concerns the construction section near the eastern portal. The rock mass environment is formed here by quarternary sediments of Dfl2 geotype that is represented predominantly b sandy clays or even clayish sands of the class CS and SC and also by Dfl3 type that is formed by medium plastic clays of the class CI, of rigid or even solid consistency. Irregular occurrence of fluvial sediments of the type Fl2, class SM, with clayish positions CI may be expected in the bottom lining of the tunnel construction especially near the section end. The respective sediments can be categorized to workability class 3 according to ČSN 73 3050 and I according to ČSN 73 6133.

The **environment is classified in the class NATM 5b and degree of excavatability III** from the viewpoint of categorizing this unit into NATM classes according to OTSKP, Annex No. 3/1, Table No. 2. We expect that tunnelling will be carried out under the groundwater table at the very end, we determine the maximum initial inflow for the whole section to be approximately 8 l/min.

Tunnelling in this environment will require special additional stabilizing measures, e.g. using special methods of foundation engineering, such as jet grouting technology etc. in order to secure the ceiling and sides of excavation. From the viewpoint of conventional tunnelling, it will be possible to employ common technology for tunnelling here without the use of blasting operations. It will be necessary to secure the excavation with primary lining during the tunnelling , e.g. with truss or TH arcs, steel meshes, locally also with spiling and it will be necessary to close the whole profile immediately and to secure the excavation by sprayed concrete. It will be necessary to secure the unreinforced part of excavation immediately and to use additional stabilization measures (anchoring of excavation face) and to leave the stabilizing support wedge at the face of excavation eventually and to take off and secure the face of excavation gradually in this type of environment.

Forming natural rock mass vault cannot be expected within this type of environment, that is why it is necessary to dimension the lining of the underground construction for the full weight of overburden.

In case of employing the „TBM“ technology by means of full-profile driving shields (mechanized tunnelling), it would concern the transition of tunnelling from soils to rocky stone masses with respect to follow-up quasi-homogeneous units.

The tunnelling by means of TM can be categorized into the tunnelling class SM 2 – tunnelling method with partial support of front face (so called transition mode) or even SM3 – tunnelling method with partial support of front face (so called closed mode) according to the German standard DIN 18312.

Residential built-up area and Brusnice tunnel (tunnel complex Blanka) are situated near to the underground construction in this section.

8.9.2 Quasihomogeneous unit 2

The quasi-homogeneous unit was divided at the chainage at km 4.590-4.730. The section is delimited by the interface of quarternary sediments of diluviofluvial origin and weathered rockbed. Fully or even heavily weathered rock masses of the Letná series of strata, geotype Ltn/W5-W4, class R6, will be reached by tunnelling in approximately 15% of the length of this section; slightly weathered shales, geotype Ltn/W3, class R5 will be reached in approximately 40% of the tunnelling length and weakly weathered shales, geotype Ltn/W2, class R4 will be reached in approximately 45% of the tunnelling length. It concerns rock mass environment disintegrable by common machinery of workability class 4 according to ČSN 73 3050 and I according to ČSN 73 6133 in case of the geotypes Ltn/W5-W4 and

Ltn/W3 and class 5 according to ČSN 73 3050 and II according to ČSN 73 6133 for the geotype Ltn/W2.

The section was evaluated in the range of 30-35 points QTS according to QTS classification and by 16-25 points according to RMR classification.

This section **is categorized into the class NATM 5a and into excavatability degree II** according to OTSKP, annex No. 3/1, table No. 2 . The tunnelling will be conducted under groundwater table and the maximum inflow of approximately 15 l/min was calculated for the whole section at the evaluation of hydrogeological conditions in the final report. From the viewpoint of conventional tunnelling, it will be possible to employ common technology for tunnelling here without the use of blasting operations. It will be necessary to secure the excavation with primary lining during the tunnelling , e.g. with truss or TH arcs, steel meshes in combination with sprayed concrete and with systematic anchoring.

Forming natural rock mass vault cannot be expected within this quasihomogeneous unit due to insufficient thickness of the rock cover above the designed construction profile (less than two diameters of the construction) and that is why rock massif concurrence cannot be taken into account at creating the primary lining.

Tunnelling in rocky environment with alternating of hard and soft rock masses will be concerned in case of using the technology of mechanized driving. These alternations may influence the tunnelling from the viewpoint of technological muck processing that may decompose to very fine grain clay particles with the possible nature of sticky clayish substance owing to the content share of clay minerals in the rock mass. The quartz content in more solid small layers of sand-clayish shale is the second aspect of disintegrating this type of rock mass, as it has substantial influence on the material abrasiveness rate with respect to disintegration tools. The actual technological properties of the rock massif and the muck are attended in the separate Chapter 8.8 and 4.3.7. The tunnelling by means of TM can be categorized into the tunnelling class SM 2 – tunnelling method with partial support of front face (so called transition mode) according to the German standard DIN 18312, namely depending on reaching loosened positions of the rock massif for elimination of induced ground surface subsidence owing to excavation face extrusion towards the excavation and gradual loosening of disrupted rock masses above the excavation.

It concerns the Class T of excavation (closed ring of tubbings) according to the standard ČSN 73 7508 Railway Tunnels (that ensues from the Swiss standard SIA NORM 198 partly).

The tunnelling of underground construction in this section will be conducted under Patočkova, Milady Horákové and U Brusnice Streets, in close proximity of the building of Culture Ministry. The 25 m deep well S18 is situated in the premises of the garden of the Culture Ministry. The actual groundwater table was verified by phone. The well is without water according to information presently; archive data specify the water table in the depth of 24.35 m, i.e. at the elevation 234.98 m. The existing well was probably negatively influenced by the construction of Blanka tunnel complex (Brusnice tunnel).

8.9.3 Quasihomogeneous unit 3

This unit was detached in the chainage of 4.730-4.825 km. It concerns environment represented only by the geotype Ltn/W1 geologically – i.e. sound shales of Letná series of strata, of strength class R3 and workability class 5 according to ČSN 73 3050 and III according to ČSN 73 6133.

The section was evaluated in the range of 39-48 points QTS according to QTS classification and by 28-41 points according to RMR classification. This section is **categorized into class NATM 4 and up to degree of excavatability I** according to OTSKP, Annex No. 3/1, table No. 2. The tunnelling will be conducted under groundwater table and the maximum inflow of approximately 12 l/min was calculated for the whole section at the evaluation of hydrogeological conditions. From the viewpoint of conventional tunnelling, it will be possible to employ common technology for tunnelling here without the use of blasting operations. Use of blasting operations is not ruled out in case of reaching thicker rock mass layers of the strength class R3 and more solid insertions of fine grain quartz sandstones. It will be necessary to secure the excavation with primary lining during the tunnelling , e.g. with truss or TH arcs, steel meshes in combination with sprayed concrete and with systematic anchoring.

Tunnelling in rocky environment with alternating of hard and soft rock masses will be concerned in case of using the technology of mechanized driving. These alternations may influence the tunnelling from the viewpoint of technological muck processing that may decompose to very fine grain clay particles with the possible nature of sticky clayish substance owing to the content share of clay minerals in the rock mass. The quartz content in more solid small layers of sand-clayish shale is the second aspect of disintegrating this type of rock mass, as it has substantial influence on the material abrasiveness rate with respect to disintegration tools.

Forming natural rock mass vault can be expected within this quasi-homogeneous unit, that is why rock massif concurrence can be taken into account at creating the primary lining.

The tunnelling by means of TM can be categorized into the tunnelling class SM 2 to SM 1 – tunnelling method with partial support of front face (so called transition mode) according to the German standard DIN 18312, namely depending on reaching loosened positions of the rock massif for elimination of induced ground surface subsidence owing to excavation face extrusion towards the excavation and gradual loosening of disrupted rock masses above the excavation.

It concerns the Class T of excavation (closed ring of tubbings) according to the standard ČSN 73 7508 Railway Tunnels (that ensues from the Swiss standard SIA NORM 198 partly).

The tunnelling of the underground construction in this section will be conducted under Patočkova Street and, then partly under Střešovice tram depot and near-by building structures – villas with cellars and gardens. These are two or three storeyed buildings.

8.9.4 Quasihomogeneous unit 4

This unit was detached in the chainage of 4.825-4.995 km. It concerns environment represented predominantly by the geotype Ltn/W1 geologically (approximately 65% of the section length) – i.e. sound shales of Letná series of strata, of strength class R3 and workability class 5 according to ČSN 73 3050 and III according to ČSN 73 6133. Two tectonic disturbance zones - geotype Ltn/TEKT (approximately 35% of the section length) - were found within this unit by exploration works. In particular at the section beginning and end, approximately where the above described rock masses are intensively tectonically disrupted and thus their physically mechanical as well as technological properties negatively influenced. With respect to tectonic disruption of the massif, the groundwater inflow to the excavation may increase locally here up to 75 l/min at maximum for the whole length of the section of tectonically disrupted zone according to the calculation. However, this is a limit (initial) value with highest probability. However, values in the order of (XX) l/min are realistic in disrupted zones. The groundwater inflow will be around 10 l/min in the non-disrupted part of the quasi-homogeneous unit according to the calculation.

The section was evaluated in the range of 31-43 points QTS according to QTS classification and by 21-34 points according to RMR classification. **This section, in case of tunnelling out of disturbance zones** (approximately 65% of the section length), is

categorized to NATM 4 class and to excavatability degree I according to OTSKP, Annex No. 3/1, Table No. 2, while in disturbance zones (approximately 35% of the section length), **this section was categorized to NATM 5a class and to degree of excavatability II.** The tunnelling will be conducted under groundwater table and the maximum inflow of approximately 75 l/min was calculated for the whole section including disrupted zones at the evaluation of hydrogeological conditions in the final report. However, this is a limit value with highest probability as already mentioned above.

From the viewpoint of conventional tunnelling, it will be possible to employ common technology for tunnelling here without the use of blasting operations. If positions of workability class 6 according to ČSN 73 3050 and III according to ČSN 73 6133 are reached that were not verified by exploration works, the use of blasting operations of small extent might be necessary, e.g. limited blast of part of the excavation. It will be necessary to secure the excavation with primary lining during the tunnelling , e.g. with truss or TH arcs, steel meshes in combination with sprayed concrete. If tectonic disturbances are reached, it will be necessary to consider e.g. By spiling the arc area of excavation face or its securing by tubing canopy or by IBO anchors.

Forming natural rock mass vault can be expected within this quasihomogeneous unit out of tectonically disrupted zones, that is why rock massif concurrence can be taken into account at creating the primary lining.

Tunnelling in rocky environment with alternating of hard and soft rock masses with transitions to tectonic disturbance zones will be concerned in case of using the technology of mechanized driving. This alternating may influence the tunnelling from the viewpoint of technological muck processing that may decompose to very fine grain clay particles with possible nature of sticky clayish substance owing to the content share of clay minerals in the rock mass.

The quartz content in more solid small layers of sand-clayish shale is the second aspect of disintegrating this type of rock mass, as it has substantial influence on the material abrasiveness rate with respect to disintegration tools. The quartz content in more solid small layers of sand-clayish shale is the second aspect of disintegrating this type of rock mass, as it has substantial influence on the material abrasiveness rate with respect to disintegration tools. However, increased pressure on the shell of the tunnelling machine may appear in case of mining into a disturbance zone. It will be left to the contractor’s consideration from this reason, whether it will be necessary to carry out e.g. advance measures before the tunnelling in these disturbance zones such as pressure grouting of the massif.

The tunnelling by means of TM can be categorized into the tunnelling class SM 2 to SM 3 – tunnelling method with partial support of front face (so called transition mode) or even tunnelling method with partial support of front face (so called closed mode) according to the German standard DIN 18312, namely depending on reaching loosened positions of the rock massif for elimination of induced ground surface subsidence owing to excavation face extrusion towards the excavation and gradual loosening of disrupted rock masses above the excavation.

It concerns the Class T of excavation (closed ring of tubbings) according to the standard ČSN 73 7508 Railway Tunnels (that ensues from the Swiss standard SIA NORM 198 partly).

The tunnelling of the underground construction in this section will be conducted under crossing of in Cukrovarnická and Patočkova Streets , then partly under Střešovice tram depot.

8.9.5 Quasihomogeneous unit 5

This unit was detached in the chainage of 4.995-6.035 km. It concerns environment represented only by the geotype Ltn/W1 geologically – i.e. sound shales of Letná series of strata, of strength class R3 and workability class 5 according to ČSN 73 3050 and III according to ČSN 73 6133.

The section was evaluated in the range of 39-49 points QTS according to QTS classification and by 32-44 points according to RMR classification. This section is **categorized into class NATM 4 and up to degree of excavatability I** according to OTSKP, Annex No. 3/1, table No. 2. The tunnelling will be conducted under groundwater table and the maximum inflow of approximately 85 l/min was calculated for the whole section at the evaluation of hydrogeological conditions in the final report From the viewpoint of conventional tunnelling, it will be possible to employ common technology for tunnelling here without the use of blasting operations. Use of blasting operations is not ruled out in case of reaching thicker rock mass layers of the strength class R3 and more solid insertions of fine grain quartz sandstones. It will be necessary to secure the excavation with primary lining during the tunnelling , e.g. with truss or TH arcs, steel meshes in combination with sprayed concrete and with systematic anchoring.

Forming natural rock mass vault can be expected within this quasi-homogeneous unit, that is why rock massif concurrence can be taken into account at creating the primary lining.

Tunnelling in rocky environment with alternating of hard and soft rock masses will be concerned in case of using the technology of mechanized driving. These alternations may influence the tunnelling from the viewpoint of technological muck processing that may decompose to very fine grain clay particles with the possible nature of sticky clayish substance owing to the content share of clay minerals in the rock mass. The quartz content in more solid small layers of sand-clayish shale is the second aspect of disintegrating this type of rock mass, as it has substantial influence on the material abrasiveness rate with respect to disintegration tools. The tunnelling by means of TM can be categorized into the tunnelling class SM 2 to SM 1 – tunnelling method with partial support of front face (so called transition mode) according to the German standard DIN 18312, namely depending on reaching loosened positions of the rock massif for elimination of induced ground surface subsidence owing to excavation face extrusion towards the excavation and gradual loosening of disrupted rock masses above the excavation.

It concerns the Class T of excavation (closed ring of tubbings) according to the standard ČSN 73 7508 Railway Tunnels (that ensues from the Swiss standard SIA NORM 198 partly).

The tunnelling of underground construction in this section will be conducted at first under the built-up area between Cukrovarnická and Střešovická Streets. Then, it leads under the Střešovická street; the section end is situated in the place of Střešovická - Na Petřinách streets crossing. Villas with cellars and gardens are situated in the short beginning section; then, the work leads under a street with operated tram line. Two up to several storeyed buildings of villa nature are situated in the vicinity of Střešovická street. Drainage galleries, marked Prokop and Ivan galleries in the layout, were identified by the geotechnical investigation in the section south of route of interest, in the distance of approximately 44-55 m in the expected area of influence of hydraulic depression. However, these galleries collect groundwater from Cretaceous aquifer, and thus the yield of groundwater inflows should not be influenced negatively owing to the tunnelling, because the tunnels will be mined in deeper aquifer bonded to the fissure collector of Ordovician rock masses.

8.9.6 Quasihomogeneous unit 6

This unit was detached in the chainage of 6.035-6.170 km. It concerns environment represented predominantly by the geotype Ltn/W1 geologically (approximately 60% of the section length) – i.e. sound shales of Letná series of strata, of strength class R3 and workability class 5 according to ČSN 73 3050 and III according to ČSN 73 6133. Larger quantity of local tectonic disturbance zones of small thickness (approximately 25 pcs) - geotype Ltn/TEKT (approximately 40 % of the section length) - were reached within this unit by exploration works (borehole HJ15) . Described rock masses are intensively tectonically disrupted, which affects their mechanical as well as technological properties negatively. With respect to tectonic disruption of the massif, the groundwater inflow to the excavation may increase locally here up to 65 l/min at maximum for the whole length of the section of tectonically disrupted zone according to the calculation. However, this is a limit (initial) value with highest probability. However, values in the order of (XX) l/min are realistic in disrupted zones. The groundwater inflow will be around 15 l/min in the non-disrupted part of the quasi-homogeneous unit according to the calculation.

The section was evaluated in the range of 30-41 points QTS according to QTS classification and by 18-30 points according to RMR classification. **This section, in case of tunnelling out of disturbance zones** (approximately 60% of the section length), **is categorized to NATM 4 class and to excavatability degree I in disturbance zones** (approximately 40% of the section length), **this section was categorized to NATM 5a class and to degree of excavatability II** according to OTSKP, Annex No. No. 3/1, Table No. 2. The tunnelling will be conducted under groundwater table and the maximum inflow of approximately 65 l/min was calculated for the whole section including disrupted zones at the evaluation of hydrogeological conditions in the final report. However, this is a limit value with highest probability as already mentioned above.

From the viewpoint of conventional tunnelling, it will be possible to employ common technology for tunnelling here without the use of blasting operations. If positions of workability class 6 according to ČSN 73 3050 and III according to ČSN 73 6133 are reached that were not verified by exploration works, the use of blasting operations of small extent might be necessary, e.g. limited blast of part of the excavation. It will be necessary to secure the excavation with primary lining during the tunnelling , e.g. with truss or TH arcs, steel meshes in combination with sprayed concrete. If tectonic disturbances are reached, it will be necessary to consider e.g. By spiling the arc area of excavation face or its securing by tubing canopy or by IBO anchors.

Forming natural rock mass vault can be expected within this quasihomogeneous unit out of tectonically disrupted zones, that is why rock massif concurrence can be taken into account at creating the primary lining.

Tunnelling in rocky environment with alternating of hard and soft rock masses with transitions to tectonic disturbance zones will be concerned in case of using the technology of mechanized driving. This alternating may influence the tunnelling from the viewpoint of technological muck processing that may decompose to very fine grain clay particles with possible nature of sticky clayish substance owing to the content share of clay minerals in the rock mass.

The quartz content in more solid small layers of sand-clayish shale is the second aspect of disintegrating this type of rock mass, as it has substantial influence on the material abrasiveness rate with respect to disintegration tools. The quartz content in more solid small layers of sand-clayish shale is the second aspect of disintegrating this type of rock mass, as it has substantial influence on the material abrasiveness rate with respect to disintegration tools. However, increased pressure on the shell of the tunnelling machine may appear in case of mining into a disturbance zone. It will be left to the contractor's consideration from this reason, whether it will be necessary to carry out e.g. advance measures before the tunnelling in these disturbance zones such as pressure grouting of the massif.

The tunnelling by means of TM can be categorized into the tunnelling class SM 2 to SM 3 – tunnelling method with partial support of front face (so called transition mode) or even tunnelling method with partial support of front face (so called closed mode) according to the German standard DIN 18312, namely depending on reaching loosened positions of the rock massif for elimination of induced ground surface subsidence owing to excavation face extrusion towards the excavation and gradual loosening of disrupted rock masses above the excavation.

It concerns the Class T of excavation (closed ring of tubbings) according to the standard ČSN 73 7508 Railway Tunnels (that ensues from the Swiss standard SIA NORM 198 partly).

The tunnelling of the underground construction in this section will be conducted under the crossing of Střešovická, Na Petřinách, and Nový lesík streets. Drainage galleries, designated as galleries Vojtěch, Norbert, and Zikmund in the layout, were identified by the geotechnical investigation in the section in the expected area of hydraulic depression influence. However, these galleries collect groundwater from Cretaceous aquifer, and thus the yield of groundwater inflows should not be influenced negatively owing to the tunnelling, because the tunnels will be mined in deeper aquifer bonded to the fissure collector of Ordovician rock masses.

8.9.7 Quasihomogeneous unit 7

This unit was detached in the chainage of 6.170-6.680 km. It concerns environment represented only by the geotype Ltn/W1 geologically – i.e. sound shales of Letná series of strata, of strength class R3 and workability class 5 according to ČSN 73 3050 and III according to ČSN 73 6133.

The section was evaluated in the range of 40-50 points QTS according to QTS classification and by 38-46 points according to RMR classification. This section is **categorized into class NATM 4 and up to degree of excavatability I** according to OTSKP, Annex No. 3/1, table No. 2. The tunnelling will be conducted under groundwater table and the maximum inflow of approximately 60 l/min was calculated for the whole section at the evaluation of hydrogeological conditions in the final report From the viewpoint of conventional tunnelling, it will be possible to employ common technology for tunnelling here without the use of blasting operations. Use of blasting operations is not ruled out in case of reaching thicker rock mass layers of the strength class R3 and more solid insertions of fine grain quartz sandstones. It will be necessary to secure the excavation with primary lining during the tunnelling , e.g. with truss or TH arcs, steel meshes in combination with sprayed concrete and with systematic anchoring.

Forming natural rock mass vault can be expected within this quasi-homogeneous unit, that is why rock massif concurrence can be taken into account at creating the primary lining.

Tunnelling in rocky environment with alternating of hard and soft rock masses will be concerned in case of using the technology of mechanized driving. These alternations may influence the tunnelling from the viewpoint of technological muck processing that may decompose to very fine grain clay particles with the possible nature of sticky clayish substance owing to the content share of clay minerals in the rock mass. The quartz content in more solid small layers of sand-clayish shale is the second aspect of disintegrating this type of rock mass, as it has substantial influence on the material abrasiveness rate with respect to disintegration tools. The tunnelling by means of TM can be categorized into the tunnelling class SM 2 to SM 1 – tunnelling method with partial support of front face (so called transition mode) according to the German standard DIN 18312, namely depending on reaching loosened positions of the rock massif for elimination of induced ground surface subsidence owing to excavation face extrusion towards the excavation and gradual loosening of disrupted rock masses above the excavation.

It concerns the Class T of excavation (closed ring of tubbings) according to the standard ČSN 73 7508 Railway Tunnels (that ensues from the Swiss standard SIA NORM 198 partly).

The tunnelling of underground construction in this section will be conducted at first under the built-up area between Cukrovarnická and Střešovická Streets. Then, it leads under the Střešovická street; the section end is situated in the place of Střešovická - Na Petřinách streets crossing. Villas with cellars and gardens are situated in the short beginning section; then, the work leads under a street with operated tram line. Two up to several storeyed buildings of villa nature are situated in the vicinity of Střešovická street.

The tunnelling of underground construction in this section will be carried out under the boundary part of Cretaceous plane in Střešovice. There is a built-up area with sporadic villa house with gardens only in the overburden of the structure , there is only one residential house with three over ground storeys in the beginning section. Drainage galleries were identified by the geotechnical investigation in the distance of approximately 37-46 m south of the route of interest in this section in the expected area of hydraulic depression influence, designated as galleries Vojtěch, Norbert, and Zikmund in the layout. However, these galleries collect groundwater from Cretaceous aquifer, and thus the yield of groundwater inflows should not be influenced negatively owing to the tunnelling, because the tunnels will be mined in deeper aquifer bonded to the fissure collector of Ordovician rock masses. According to archive map documents (Basic EG map 1 : 5 000, sheet P 8-0), the construction passes under territory evaluated as steadied aerial landslide. The given territory is not included in the register of slope instability and slides of the archive of Czech Geological Service - Geofond Praha. The negative impacts of the tunnel mining on the ground surface must be eliminated during the execution of the given construction section. We consider as necessary to establish a system of monitoring movements of slopes and rock blocks (Natural monument Střešovice Rocks) in the given construction section in advance before the construction start.

8.9.8 Quasihomogeneous unit 8

This unit was detached in the chainage of 6.680-6.770 km. It concerns environment represented predominantly by the geotype Dbr/W1 geologically (approximately 60% of the section length) – i.e. sound shales of Dobrotivian series of strata, of strength class R4 and workability class 5 according to ČSN 73 3050 and II according to ČSN 73 6133. We expect within this unit that the tectonic disturbance zone - geotype Dbr/TEKT (approximately 40% of the section length) is reached at the section beginning in contact with rock masses of geotype Ltn/W1 of the previous quasihomogeneous unit 7 based on the study of geological maps where the above described rock masses are intensively tectonically disrupted and thus their physically mechanical as well as technological properties negatively influenced. Increased groundwater inflow into the excavation may locally occur here of up to 170 l/min at maximum over the whole length of disturbance zone unit according to calculation with respect to the tectonic disruption of the massif. However, this is a limit value with highest probability. However, values in the order of (XX) l/min are realistic in disrupted zones. The groundwater inflow will be around 55 l/min in the non-disrupted part of the quasi-homogeneous unit according to the calculation.

The section was evaluated in the range of 30-38 points QTS according to QTS classification and by 18-28 points according to RMR classification. This **section, in case of tunnelling out of disturbance zones** (approximately 60% of the section length), is **categorized to NATM 4 class and to excavatability degree I in disturbance zones** (approximately 40% of the section length)**, this section was categorized to NATM 5a class and to degree of excavatability II** according to OTSKP, Annex No. No. 3/1, Table No. 2. The tunnelling will be conducted under groundwater table and the maximum inflow of approximately 170 l/min was calculated for the whole section including disrupted zones in the evaluation of hydrogeological conditions in the final report. However, it is a limit value most probably, as already mentioned above.

From the viewpoint of conventional tunnelling, it will be possible to employ common technology for tunnelling here without the use of blasting operations. If positions of workability class 6 according to ČSN 73 3050 and III according to ČSN 73 6133 are reached that were not verified by exploration works, the use of blasting operations of small extent might be necessary, e.g. limited blast of part of the excavation. It will be necessary to secure the excavation with primary lining during the tunnelling , e.g. with truss or TH arcs, steel meshes in combination with sprayed concrete. If tectonic disturbances are reached, it will be necessary to consider e.g. By spiling the arc area of excavation face or its securing by tubing canopy or by IBO anchors.

Forming natural rock mass vault can be expected within this quasihomogeneous unit out of tectonically disrupted zones, that is why rock massif concurrence can be taken into account at creating the primary lining.

Tunnelling in rocky environment with alternating of hard and soft rock masses with transitions to tectonic disturbance zones will be concerned in case of using the technology of mechanized driving. This alternating may influence the tunnelling from the viewpoint of technological muck processing that may decompose to very fine grain clay particles with possible nature of sticky clayish substance owing to the content share of clay minerals in the rock mass.

The quartz content in more solid small layers of sand-clayish shale is the second aspect of disintegrating this type of rock mass, as it has substantial influence on the material abrasiveness rate with respect to disintegration tools. The quartz content in more solid small layers of sand-clayish shale is the second aspect of disintegrating this type of rock mass, as it has substantial influence on the material abrasiveness rate with respect to disintegration tools. However, increased pressure on the shell of the tunnelling machine may appear in case of mining into a disturbance zone. It will be left to the contractor's consideration from this reason, whether it will be necessary to carry out e.g. advance measures before the tunnelling in these disturbance zones such as pressure grouting of the massif.

The tunnelling by means of TM can be categorized into the tunnelling class SM 2 to SM 3 – tunnelling method with partial support of front face (so called transition mode) or even tunnelling method with partial support of front face (so called closed mode) according to the German standard DIN 18312, namely depending on reaching loosened positions of the rock massif for elimination of induced ground surface subsidence owing to excavation face extrusion towards the excavation and gradual loosening of disrupted rock masses above the excavation.

It concerns the Class T of excavation (closed ring of tubbings) according to the standard ČSN 73 7508 Railway Tunnels (that ensues from the Swiss standard SIA NORM 198 partly).

The tunnelling of underground construction in this section will be conducted under the boundary of Cretaceous plane in Střešovice, without surface built-up area. The tunnelling will carried out in Na Petřinách street with the operated tram line and its close vicinity. The extraction adit of the Castle Water Duct was identified by the geotechnical investigation roughly around the chainage of km 6.490 and at the section end in the assumed area of influence of the hydraulic depression. It is marked in the layout as galleries No. 4, 5, and 6. However, these galleries collects groundwater from Cretaceous aquifer, and thus the yield of groundwater inflows should not be influenced negatively owing to the tunnelling, because the tunnels will be mined in deeper aquifer bonded to the fissure collector of Ordovician rock masses. As part of this quasi-homogeneous unit, the tunnelling will partly take place under the Natural monument Střešovice Rocks. According to archive map documents (Basic EG map 1 : 5 000, sheet P 8-0), the construction passes under territory evaluated as steadied aerial landslide. The given territory is not included in the register of slope instability and slides of the archive of Czech Geological Service - Geofond Praha. The negative impacts of the tunnel mining on the ground surface must be eliminated during the execution of the given construction section. We consider as necessary to establish a system of monitoring movements of slopes and rock blocks (Natural monument Střešovice Rocks) in the given construction section in advance before the construction start.

8.9.9 Quasihomogeneous unit 9

This unit was detached in the chainage of 6.680-7.230 km. It concerns environment represented only by the geotype Dbr/W1 geologically - i.e. sound shales of the Dobrotivian series of strata, of strength class R4 and workability class 5 according to ČSN 73 3050 and II according to ČSN 73 6133.

The section was evaluated in the range of 38-47 points QTS according to QTS classification and by 34-41 points according to RMR classification.

This section is **categorized into class NATM 4 and up to degree of excavatability I** according to OTSKP, Annex No. 3/1, table No. 2. The tunnelling will be conducted under groundwater table and the maximum inflow of approximately 15 l/min was calculated for the whole section at the evaluation of hydrogeological conditions in the final report. From the viewpoint of conventional tunnelling, it will be possible to employ common technology for tunnelling here without the use of blasting operations. It will be necessary to secure the excavation with primary lining during the tunnelling , e.g. with truss or TH arcs, steel meshes in combination with sprayed concrete and with systematic anchoring.

Forming natural rock mass vault cannot be expected within this quasi-homogeneous unit, that is why rock massif concurrence cannot be taken into account at creating the primary lining.

Tunnelling in rocky environment with sporadical alternating of hard and soft rock masses will be concerned in case of using the technology of mechanized driving. This alternating may influence the tunnelling from the viewpoint of technological muck processing that may decompose to very fine grain clay particles with possible nature of sticky clayish substance owing to the content share of clay minerals in the rock mass. The tunnelling by means of TM can be categorized into the tunnelling class SM 2 – tunnelling method with partial support of front face (so called transition mode) according to the German standard DIN 18312. It concerns the Class T of excavation (closed ring of tubbings) according to the standard ČSN 73 7508 Railway Tunnels (that ensues from the Swiss standard SIA NORM 198 partly).

The tunnelling of underground construction in this section will be conducted under the boundary of Cretaceous plane in Střešovice, with discontinuous (sporadic) surface built-up area. The tunnelling will carried out in Na Petřinách street with the operated tram line and its close vicinity and then under the U Šesté Baterie street; its edge will even extend to the north part of the premises of the Střešovice Central Military Hospital. It will reach under the premises of the heating plant in Veleslavín at the section end.

Collecting galleries of the Castle Water Duct were identified by the geotechnical investigation in the assumed area of influence of the hydraulic depression in the initial section and in the chainage of approximately 6,975 km. They are marked as galleries No. 3 and 4 in the layout. However, these galleries collects groundwater from Cretaceous aquifer, and thus the yield of groundwater inflows should not be influenced negatively owing to the tunnelling, because the tunnels will be mined in deeper aquifer bonded to the fissure collector of Ordovician rock masses. As part of this quasi-homogeneous unit, the tunnelling will partly take place under the Natural monument Střešovice Rocks in the initial section. According to archive map documents (Basic EG map 1 : 5 000, sheet P 8-0), the construction passes under territory evaluated as steadied aerial landslide. The given territory is not included in the register of slope instability and slides of the archive of Czech Geological Service - Geofond Praha. The negative impacts of the tunnel mining on the ground surface must be eliminated during the execution of the given construction section. We consider as necessary to establish a system of monitoring movements of slopes in the given construction section in advance before the construction start.

8.9.10 Quasihomogeneous unit 10

This unit was detached in the chainage of 7.230-7.322 km. As regards geology, it is an environment represented by Dbr/W2 geotype (approximately 75% of the section length) – i.e. by weathered shales of Dobrotivian series of strata, of R4/R5 strength class and 4-5 workability class according to ČSN 73 3050 and I-II workability class according to ČSN 73 6133. We expect within this unit that the tectonic disturbance zone - geotype Dbr/TEKT (approximately 25% of the section length) is reached according to evaluation of new exploration works where the above described rock masses are intensively tectonically disrupted and thus their physically mechanical as well as technological properties negatively influenced. Increased groundwater inflow into the excavation may locally occur here of up to 125 l/min at maximum over the whole length of disturbance zone unit according to calculation with respect to the tectonic disruption of the massif. However, this is a limit value with highest probability. However, values in the order of XX l/min are realistic in disrupted zones. The groundwater inflow will be around 10 l/min in the non-disrupted part of the quasi-homogeneous unit according to the calculation.

The section was evaluated in the range of 34-40 points QTS according to QTS classification and by 22-32 points according to RMR classification. This section **is categorized into the class NATM 5a and into excavatability degree II** according to OTSKP, annex No. 3/1, table No. 2. The tunnelling will be conducted under groundwater table and the maximum inflow of approximately 125 l/min was calculated for the whole section including disrupted zones at the evaluation of hydrogeological conditions in the final report. However, this is a limit value with highest probability as already mentioned above.

From the viewpoint of conventional tunnelling, it will be possible to employ common technology for tunnelling here without the use of blasting operations. If positions of workability class 6 according to ČSN 73 3050 and III according to ČSN 73 6133 are reached that were not verified by exploration works, the use of blasting operations of small extent might be necessary, e.g. limited blast of part of the excavation. It will be necessary to secure the excavation with primary lining during the tunnelling , e.g. with truss or TH arcs, steel meshes in combination with sprayed concrete. If tectonic disturbances are reached, it will be necessary to consider e.g. By spiling the arc area of excavation face or its securing by tubing canopy or by IBO anchors.

Forming natural rock mass vault can be expected within this quasihomogeneous unit out of tectonically disrupted zones, that is why rock massif concurrence can be taken into account at creating the primary lining.

Tunnelling in rocky environment with alternating of hard and soft rock masses with transitions to tectonic disturbance zones will be concerned in case of using the technology of mechanized driving. This alternating may influence the tunnelling from the viewpoint of technological muck processing that may decompose to very fine grain clay particles with possible nature of sticky clayish substance owing to the content share of clay minerals in the rock mass.

The quartz content in more solid small layers of sand-clayish shale is the second aspect of disintegrating this type of rock mass, as it has substantial influence on the material abrasiveness rate with respect to disintegration tools. The quartz content in more solid small layers of sand-clayish shale is the second aspect of disintegrating this type of rock mass, as it has substantial influence on the material abrasiveness rate with respect to disintegration tools. However, increased pressure on the shell of the tunnelling machine may appear in case of mining into a disturbance zone. It will be left to the contractor's consideration from this reason, whether it will be necessary to carry out e.g. advance measures before the tunnelling in these disturbance zones such as pressure grouting of the massif.

The tunnelling by means of TM can be categorized into the tunnelling class SM 2 to SM 3 – tunnelling method with partial support of front face (so called transition mode) or even tunnelling method with partial support of front face (so called closed mode) according to the German standard DIN 18312, namely depending on reaching loosened positions of the rock massif for elimination of induced ground surface subsidence owing to excavation face extrusion towards the excavation and gradual loosening of disrupted rock masses above the excavation.

It concerns the Class T of excavation (closed ring of tubbings) according to the standard ČSN 73 7508 Railway Tunnels (that ensues from the Swiss standard SIA NORM 198 partly).

The tunnelling of underground construction in this section will be conducted under the premises of the heating plant in Veleslavín. The course of the Castle Water Duct was identified at the geotechnical investigation in the expected influence area of the hydraulic depression roughly around the chainage at km 7.245 of this section

8.10. EXCAVATION OF STŘEŠOVICE AIR SHAFT SO 06-25-04, KM 5.795

Geological conditions in the area of technology object Střešovice are apparent from the geotechnical cross section that is included in the annex No. 3.4. This cross-section was made up on the basis of documentation of the new exploration borehole J6 above all. Furthermore, the terrain morphology and generally known bedding conditions of upper Cretaceous sediments and Ordovician sedimentary rock masses were taken into consideration.

Made-grounds of small thickness with the nature of dug up local soils with admixture of construction waste and aggregate will be generally reached during the excavation from the ground surface, with humous, grassed covered reclamation layer at the top. Lower, to the depth of approximately 13-15 we expect reaching thick solifluction (deluvial) sediments, predominantly of the nature of sandy clay, locally even clayish sand, with sporadic positions of medium plastic clay. The given sediments were predominantly of rigid to solid consistency; the clayish sands were evaluated as medium compacted. Silty shales, slightly weathered, strongly folded, with very high or even extreme density of discontinuities, of R5/R6 strength class were reached by the borehole from the depth of 14.8 m. Then, the borehole reached weakly weathered sandy shales, limonitized in fissures, of R4/R5 strength class in the 18.8-21.5 m depth interval. The exploration well was terminated in sound silty shales, with irregular lamina of fine grain quartz sandstone - Letná series of strata – Ordovician.

The groundwater table was tapped in the depth of 12.0 m under the terrain surface in the J6 borehole. It concerns environment of deluvial sediments. It concerns intrinsic water regimen in the given environment, groundwater is supplied by atmospheric precipitation only, eventually by seepages from leaking underground services (water mains, sewerage). Due to the drilling technology (diamond drilling with water flush from 16.0 m), it was not possible to specify the level of water bound in fissures occurring deeper in Ordovician collector.

The data were summarized in a table based on the above mentioned geotechnical section within the geotechnical evaluation of the shaft excavation where they reached geotechnical type, symbol of soils and rock masses representing it, workability class according to the already invalid, but still used standard ČSN 73 3050 and standard ČSN 73 6133 is defined in each row, always related to depth.

Tab. 8.10.a: Geotechnical evaluation of the excavation of Střešovice Air Shaft SO 06-25-04

Air shaft Střešovice						
Assumption of reach groundwater table		1st groundwater table 12.0 m under ground level				
depth to (m)	GT type	ČSN P 73 1005	workability class		type of earthwork support
		class/ symbol	ČSN 73 3050	ČSN 73 6133	
1.3	An – anthropogennic made grounds + reclamation hum. horizon	F3/MSY S4/SMY F5/MIO	3	I	re-bored pile walls, interlocking pile
3.0	Eol1 – eolian-deluvial sediments	F4/CS F6/CI	3	I	re-bored pile walls, interlocking pile
5.5	Dl2 – deluvial sediments	F4/CS	3	I	re-bored pile walls, interlocking pile
9.8	Dfl2– deluviofluvial sediments	S5/SC	3	I	re-bored pile walls, interlocking pile
14.8	Dl2 – deluvial sediments	F4/CS	3	I	re-bored pile walls, interlocking pile
18.8	Ltn/W3 –slightly weathered silty shales of Letná series of strata - Ordovician	R5/R6	3-4	I-II	re-bored pile walls, interlocking pile
21.5	Ltn/W2 – weakly weathered silty shales of Letná series of strata - Ordovician	R4/R5	4-5	II	re-bored pile walls, interlocking pile
72.0	Ltn/W1 - sound silty shales Letná series of strata - Ordovician	R4-R3	5	III	re-bored pile walls, interlocking pile

Soils and rock masses of workability classes 3-5 according to ČSN 73 3050 and I-III according to ČSN 73 6133 will occur at excavation of shafts. We recommend based on processing the results of geotechnical investigation from several aspects to carry out earthwork support of the pit in advance by means of special methods of foundation engineering such as re-bored pile wall, or interlocking pile so that they fulfil the supporting as well as sealing function.

9. GEOTECHNICAL MONITORING

Mining the tunnels influences the surrounding rock massif, changes its original tension and causes its deformations. This action is partly transmitted to the surface built-up area, underground services and other constructions and therefore, the project design documentation of Střešovice tunnels must also respect requirements for their protection. It is based on the estimated or calculated extent and course of deformations of the rock massif and on allowable values of relative deformations determined by standards or calculations that will not disturb the concerned structures. Therefore, it is necessary to execute a geotechnical monitoring in order to monitor the tension-deformation behaviour of the rock massif, the bearing system of primary lining and the deformations at the surface and at the built-up area or at other structures; it consists usually of following components and measurements above all and its structure depends on the used system of tunnelling (cyclic tunnelling – e.g. NATM or mechanized tunnelling by means of full-profile driving machines - shields)

- measurement of shape changes of the excavation - convergence
- stress measurement in sprayed concrete primary lining (at NATM)
- measurement of stress at the contact of reinforcement and rock massif
- condition survey of overground built-up area, underground structures, underground services and underground roads
- condition survey of wells and bored wells for heat pumps
- measurement of deformations at the surface of territory of interest
- measurement of deformations at building structures
- measurements at underground services
- measurement of strength of sprayed concrete (at NATM)
- dynamic, seismic and acoustic measurements especially, if blasting operations are used
- documented measurements of bearing capacity of apex stones
- dynamometric measurements on anchors
- inclinometric measurements
- extensometric measurements of deformations of the tunnels overburden
- geological documentation of mined as well as cut-and-cover parts
- monitoring of groundwater table in boreholes and wells
- monitoring groundwater inflows from the collecting galleries of the Castle Water Duct
- monitoring geodynamic movements in the area of the Natural Monument Střešovice Rocks, approximately in the section of km approx 5.900-7.100 km chainage – fixing crackmeters and 3D dilatometers to the disintegrated rock massif

It will be necessary for the execution of geotechnical monitoring with respect to its extent to elaborate project design of geotechnical monitoring that will determine warning conditions for individual structures, underground services and ground surface. The responsible project designer will determine the extent of influence of activity carried out by mining manner. Recommendations for subsequent phases of geotechnical investigation.

10. RECOMMENDATIONS FOR SUBSEQUENT PHASES OF GEOTECHNICAL INVESTIGATION

We recommend to verify the extent of quaternary sediments in the area at the eastern mined entrance portal for subsequent phases of geotechnical investigation.

- we recommend to execute a set of geophysical measurements in longitudinal profiles above the tunnels and in lateral profiles in the area of Milady Horákové, U Prašného mostu, Patočkova and U Brusnice Streets in the first phase in order to specify more precisely the course of surface of the rockbed
- subsequently, already in targeted way, to execute core boreholes in the areas of mentioned streets based on results of the geophysical survey
- It is also possible to consider an exploration gallery that would undoubtedly verify the extent of quaternary sediments in the profile as well as in the immediate overburden of the tunnels. However, it is also necessary to take into account the deformation effects of the exploration gallery mined in soils on the surface built-up area and the underground services in this decision making.

To verify the level of groundwater table both in the area of Střešovice plane formed by Ordovician rock masses and the level of groundwater table in Cretaceous rock masses by means of HG boreholes.

- The level of groundwater table in Ordovician rock masses under Cretaceous rock masses is presently verified by logging measurement only and it is important for dimensioning the permanent lining of the tunnel
- The level of groundwater table in Cretaceous sediments is important both for the design of Střešovice Air Shaft and for the extent of eventual influence on Cretaceous aquifer during its excavation. Therefore, it would be reasonable to execute a HG borehole in the area where the collecting galleries of the Castle Water Duct are nearest to the route of the tunnels.
- Executing the survey to verify slope movements in the area of the Natural monument Střešovice Rocks – inclinometric a HG monitoring boreholes.

To add exploration boreholes between the borehole HJ 16 and boreholes near the mined exit portal (HJ 8 and PJ9) for hypothetical verification of the position of very solid Skalka quartzites with difficult borability and disintegrability in the route of tunnels (occurrence of strip of quartzites cannot be ruled out in the underbed of Cretaceous sediments).

11. CONCLUSION

The following 16 new survey boreholes were executed in the scope of Střešovice mined tunnels, out of that 5 were pressiometric boreholes, 4 hydrogeological boreholes, logging measurements were performed in 4 boreholes and dilatometric measurements were performed in three boreholes.

Mined constructions of the Střešovice tunnel must be classified in **3rd geotechnical category** in terms of ČSN EN 1997-1, to which buildings belong with demanding structure in complicated geological conditions and with consideration of geotechnical risks of the construction.

The engineering-geological conditions of mining the Střešovice railway tunnels were assessed based on evaluating the conclusions of the geotechnical investigation. The whole route was divided into 9 quasi-homogeneous units in total that were determined based on the occurrence of individual geotechnical types of rock mass in the profile of the underground construction and based on wider engineering-geological and hydrogeological conditions.

Minimum scope of geomonitoring during the tunnelling was also recommended for the whole route of mining the Střešovice tunnels and areas and objectives of follow-up exploration works were also recommended for the subsequent phases of geotechnical investigation.

It can be stated in the conclusion that the survey objective, i.e. becoming preliminary acquainted with geological and hydrogeological environment, was fulfilled. The drilling works, field measurement (pressiometric, logging, dilatometric and hydrogeological) and laboratory works provided complex of findings that were used for more precise elaboration geological model of the territory of interest.