CURRENT PROGRESS IN THE PREPARATION OF THE STŘEŠOVICE TUNNEL

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ABSTRACT: The Dejvice–Veleslavín railway tunnel, also known as the Střešovice tunnel, is a key part of a larger modernization of the railway infrastructure that will connect the center of Prague and all metro lines with Václav Havel Airport and Kladno. This article follows the process of selecting the most suitable route for the new underground railway connection. Its aim is to show how views on urban planning and sustainable development have changed over time and how these changes have influenced the design of the project. The text focuses not only on the technical aspects of the solution, but also on the impact of the construction on the surrounding environment, which played a role in deciding on the final variant. Finally, it also focuses on measures to reduce the impact of vibrations from railway traffic in the tunnel on the surrounding buildings.

1. INTRODUCTION

The main objective of the Prague Airport – Kladno (PRAK) rail link project is to provide a fast, high-capacity connection between Kladno, the largest city in the Central Bohemian Region, Václav Havel Airport, the largest airport in the Czech Republic, all three lines of the Prague metro, and the center of Prague. A basic description of the project's construction elements is provided in Table 1.

Table 1: Basic characteristics of the project

Parameter	Description
Lenght of the route	37,2 km double-track route (28,1 km following the historic alignment, 9,1 km new alignment)
Number of stations	17 overground and 4 underground
Cut and cover tunnels	6.0 km
Excavated tunnels	Ca 3,15 km (TBM)
Number of bridges	7

To a certain extent, the PRAK project follows the old single-track railway line between Kladno and Prague, but in some parts it deviates from it, and the connection to the airport is completely new. The project is divided into 10 construction units. The first section was built between 2017 and 2020, two sections are scheduled to begin construction in 2022, and the rest will follow by 2028. The project is scheduled for completion in 2030. The total investment cost of the project is estimated at CZK 50 billion (EUR 2 billion).

This article focuses on the Dejvice - Veleslavín construction section with two single-track tunnels (TBM). This 3.2 km long section represents approximately one tenth of the project costs.

2. HISTORY OF THE PROJECT

The project has been prepared several times in various modifications and with varying degrees of detail, and has subsequently been regularly cancelled, usually due to high investment costs. Given its location in the center of Prague, the project is also characterized by the high complexity of its preparation, particularly in terms of gaining acceptance from local and state authorities as well as the public.

2.1 SECTION DEJVICE - VELESLAVÍN

The proposal drafted between 1999 and 2005 pursued the relatively least financially demanding option of a surface double-track line following the route of the old Prague-Kladno line. This option was based on design work carried out around 1990 and proved to be no longer feasible. The Prague districts of Dejvice and Veleslavín are located relatively centrally, less than 2 km from Prague's major tourist attractions. Land prices in this area are high, and the old railway line creates an artificial barrier within the city. Therefore, a search began for an underground route that would free up the old railway line for a public promenade and park.

The so-called TUNNELED option was developed, which copies the original route, but at a greater depth. This option seemed acceptable to the general public, but the project never reached the building permit stage in this state, and all work on it was halted in 2009.

Work on the railway connection project resumed in 2012. The CUT-AND-COVER option was further developed, but certain difficulties in future implementation began to emerge. It was not possible to implement all sections using the cut-and-cover method, and therefore parts had to be designed as excavated tunnels with very shallow overburden. In some sections, there were also problems with an unacceptable risk of damage to buildings during implementation, and overall, this option began to appear unacceptable to the public due to the significant disruption to the surrounding environment during construction.

In 2016, the CUT-AND-COVER option was abandoned and new options for long bored tunnels allowing construction using TBMs were explored. The route was sought regarding the highest possible overburden in order to limit the effects of construction, such as settlement, and operation, such as vibrations on surrounding buildings. Based on a subsoil survey conducted between 2018 and 2019 and vibration measurements taken near the Institute of Physics of the Czech Academy of Sciences, the route was set approximately 110 m north of the institute to reduce the risk of disruption to scientific equipment in the laboratories. This option is further referred to as the NORTH excavated option.

Based on a public initiative from early 2019 and a subsequent resolution by the Prague 6 Municipal Council, a modification of the tunnel route was reviewed. Its purpose was to eliminate the impact on the geologically complex area near the Bruska reservoir and minimize the impact on existing buildings. The designer proposed a new variant, hereinafter referred to as the SOUTH excavated variant, leading in the vicinity of the Blanka tunnels on the City Ring Road and Milady Horákové Street.

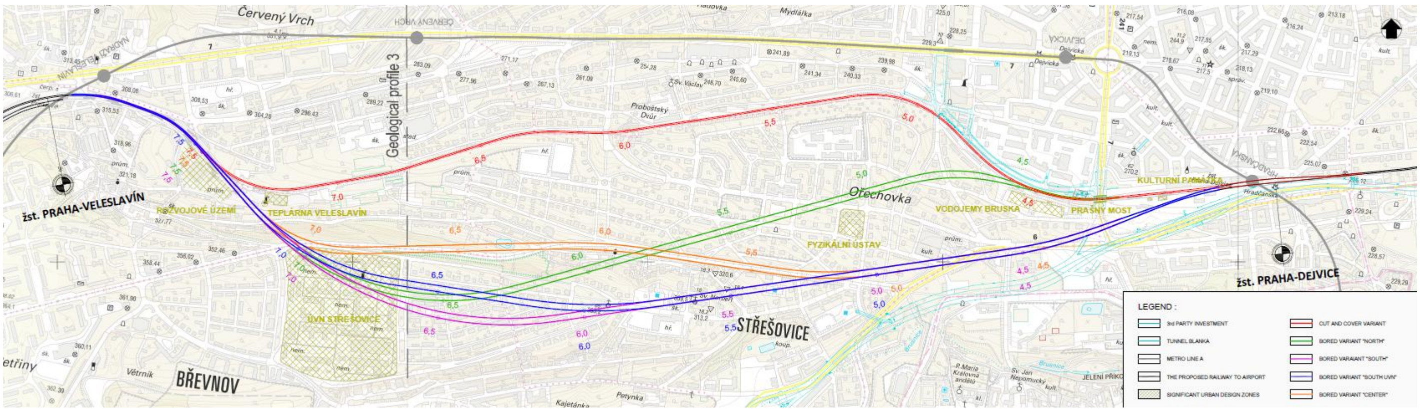

Figure 1: Layout of the investigated variants for the new connection between Prague-Dejvice and Prague-Veleslavín (red – overground and cut and cover variant; green– NORTH variant (TBM), violet– SOUTH variant (TBM), orange – Variant MIDDLE (TBM) a blue – variant SOTH-UVN (TBM)

At the initiative of the Střešovice civic association, a modified SOUTH variant, hereinafter referred to as the CENTER excavated variant, was prepared in the fall of 2019. This variant has a slightly modified route to a greater extent under the existing streets but with a lower overburden.

It can be noted that the project ultimately offered a relatively large number of routing options (Figure 1). Several assessments were carried out to evaluate their advantages and disadvantages. The overall assessment was carried out by the designer, Metroprojekt (Bednařík et al., 2020). A peer review comparing the variants in terms of tunnel excavation and the impact on the surrounding area during construction was carried out by Thewes et al. (2020). An assessment of the impact of vibrations on buildings and equipment above the tunnel and comparative in-situ measurements in the Ejpovice tunnel were carried out by Brož et al. (2020). Finally, the assessment in terms of geological conditions and reinterpretation of geological surveys was carried out by the Czech Geological Survey (Aue et al., 2020). The teams unanimously assessed the CUT-AND-COVER option as the least suitable, mainly due to the impact of tunnel construction and operation on residents, technical complexity, and risks associated with some cut and conventionally excavated tunnel sections.

The NORTH variant followed the SOUTH variant by a large margin. It was evaluated as less suitable than the CENTER and SOUTH variants due to a longer shallow section in Quaternary sediments and the associated higher risk of impact on buildings and facilities in the overburden. The CENTER and SOUTH options were evaluated similarly, but with a preference for the SOUTH option due to the expected better geological conditions north of the north-south tectonic fault anticipated in the western part of the route. Another aspect was that the CENTER variant passes under the foot of the Střešovice slope, which is unstable. Based on these assessments, the Railway Administration selected the SOUTH variant for the further project process, preparation of the EIA, and documentation for the issuance of the zoning and building permits.

In 2024, the SOUTH-ÚVN variant, which is a rectification of the originally selected SOUTH variant, was additionally reviewed. Based on an agreement between the Ministry of Defense of the Czech Republic and the Ministry of Transport of the Czech Republic, a minor correction of the route was made in the area of the Central Military Hospital in Střešovice. This correction consists of shifting the route away from buildings where oncological treatment and research using proton technologies and other highly sensitive equipment are carried out. This partial modification of the route will eliminate the impact of the route's operation and construction on these extremely sensitive devices.

At the end of 2025, the Ministry of the Environment issued a positive binding EIA opinion on the Střešovice tunnels project in the SOUTH-ÚVN variant.

3. ASSESSMENT OF VIBRATIONS CAUSED BY TUNNEL OPERATION

Vibrations caused by underground rail transport and their potential impact on life above ground are a frequent cause for public concern. Estimating vibrations at the design stage is problematic due to the large number of unknown factors that influence the propagation and attenuation of vibrations in space. For this reason, it is advisable to verify the initial assumptions from the design stage by taking in-situ measurements after the tunnel has been completed but before the final laying of the fixed track, in order to maximize the effect of the damping system.

At this stage of the project, we assume that the risk of vibration perception on the surface is very low. The distance between the tunnel and residential buildings is relatively large even at the closest point – 13 m – and this distance increases very quickly. The overburden in these shallower parts of the tunnel consists of cohesive soils. This "soft" soil environment dampens the transmission of vibrations very well. Once the tunnel enters the rock environment, it is already located deep enough (30-80 m) to significantly dampen vibrations even in this "harder" rock environment.

To verify the impact of tunnel traffic on the surface and buildings, vibration measurements were carried out (Brož et al., 2020) on an existing tunnel in operation. The Ejpovice tunnel, which is very similar to our proposed Dejvice-Veleslavín tunnel, was chosen as an ideal model case. It is a relatively new tunnel consisting of two single-track tunnel tubes excavated using a TBM. The rock environment of the Ejpovice tunnel appears to be similar, or slightly less favorable for vibration transmission (it consists mainly of shales and harder spilites), the depth of the tunnel is similar, there is a fixed track in the tunnel, the tunnel is designed for freight and passenger transport at speeds of up to 160 km/h (the Střešovice tunnel is only expected to carry passenger transport at speeds of 120 km/h), and the Ejpovice tunnel runs largely through open countryside, so no other sources of vibration interfered with the measurements. This made it possible to easily identify even small vibrations on the surface caused by passing trains.

Measurements were taken at several locations in the tunnel and on the surface in the summer of 2020. The measured values of vibration velocity amplitude on the surface were always very small, so it was not necessary or even possible to look for any relationship between the magnitude of the measured vibrations and the type or speed of individual trains in the tunnel (for example, differences between freight and passenger transport were not apparent).

The measurements also showed that the vibrations caused by road traffic at a distance of 450 m were significantly higher than those caused by rail traffic 60 m below the surface (Fig. 2).

The measured surface vibrations caused by trains passing through the tunnel were in the order of v = 0.005 mm/s, in the frequency band 40-60 Hz. After conversion, the corresponding acceleration amplitude value is in the order of A = 0.15 mm/s2 and the vibration acceleration value Law, T = 44 dB. The ČSN 73 0040 standard specifies the limit values of the limit amplitude of vibration velocity at which the initial signs of damage to building structures appear. For residential brick buildings, the standard specifies a value of 2.8 mm/s, which is significantly higher than the value measured above the Ejpovice tunnels.

The impact of vibrations on humans in the Czech Republic is defined in environmental standards through limits for vibration acceleration levels. For residential rooms, the hygienic limit for vibrations during the day is set at Law,T = 81 dB (aew,T = 11.2 mm/s2) and at night at 78 dB (aew,T = 8.0 mm/s2). The measured values of vibration acceleration (Law,T = 44 dB) and acceleration amplitude (aew,T = 0.15 mm/s2) comply with the above regulation.

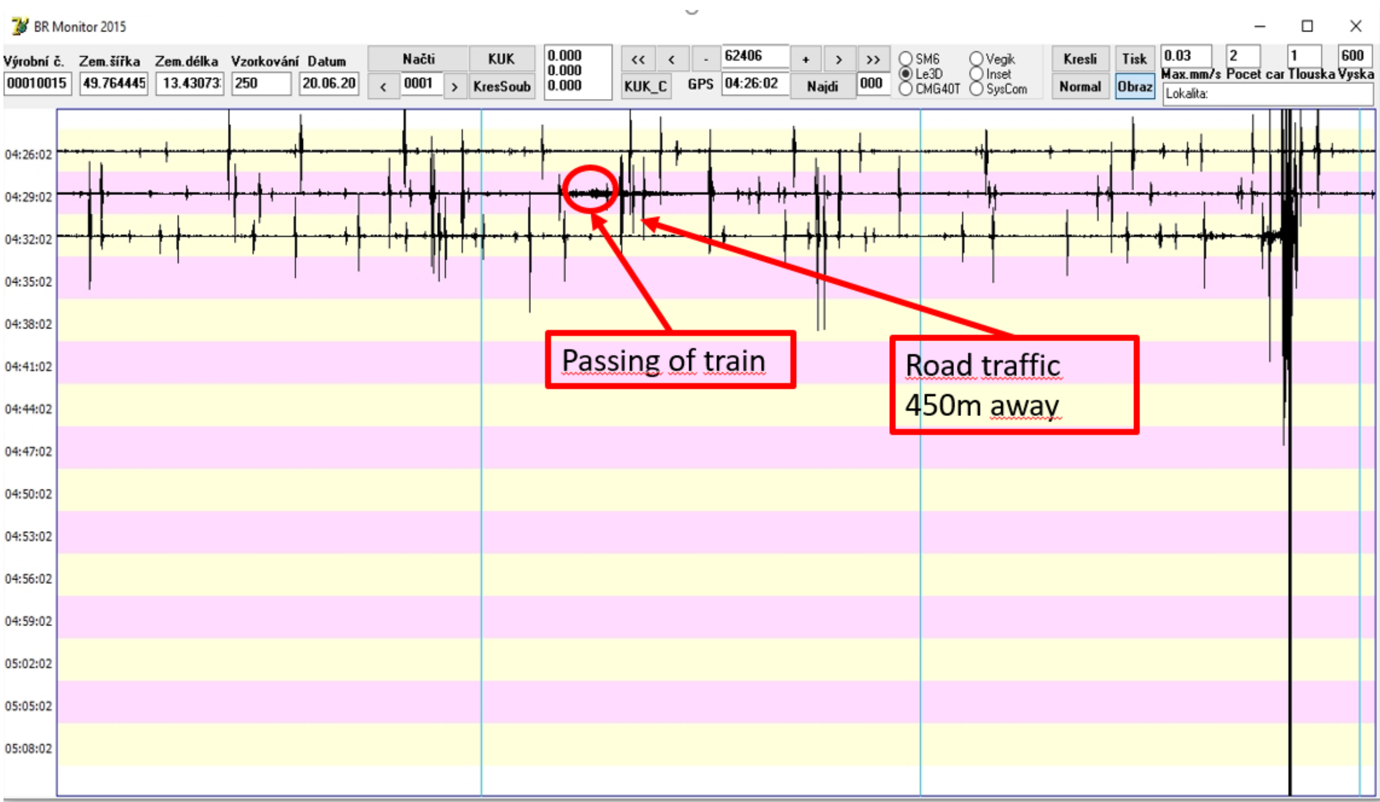

Figure 2: Time-lapse image of seismic effects caused by a train passing through the Ejpovice tunnel and effects of car traffic at a distance of approx. 450 m from the tunnel axis (Brož et al., 2020)

Similarly, BS 5228-2: 2009 specifies a vibration velocity of 0.14-0.30 mm/s as the threshold value for human perception. BS 6472-1: 2008 specifies an acceleration amplitude of A = 10-20 mm/s2 as the threshold of human perception. In both cases, the vibrations measured above the Ejpovice tunnel were significantly lower.

The measurements taken in the Ejpovice tunnel confirmed the assumptions and provided factual certainty that the damping of vibrations propagating through the rock environment will most likely be sufficient and that the vibrations on the surface will not be perceptible to human senses. For final verification of the assumptions, local measurements will be carried out in the completed tunnel before the solid roadway is constructed, e.g., using a so-called Vibroscan. If necessary, anti-vibration measures will be installed inside the tunnel and tuned based on in-situ measurements.

4. GEOTECHNICAL CONDITIONS FOR TBM EXCAVATIONS

In 2018, 2019, and 2024, preliminary geotechnical surveys were conducted for various variants of the Střešovice tunnels (Dragoun et al., 2019, 2024, and Chmelař et al., 2019). In the eastern part of the tunnel route (Dejvice portal), a thick layer of Quaternary cover was found, which will extend below the bottom of the tunnels. The Quaternary cover consists of aeolian and deluviofluvial sediments overlying the fluvial terrace sediments of the Dejvice terrace. The thickness of the Quaternary sediments reaches up to 36 m. At the western (Veleslavín) portal, the proposed tunnel does not extend into the Quaternary sediments, but the bedrock is strongly tectonically disturbed with expected high groundwater inflows. Most of the tunneling work will take place in rock conditions consisting of Paleozoic Ordovician rocks represented by the Dobrotiv (Od), Libeň (Oln), and Letná (Olt) formations – mainly shales (Fig. 3).

In the Střešovice area, the Ordovician rocks are subhorizontally overlain by relics of Mesozoic Upper Cretaceous rocks, which are represented from below by Peruc marls (Kp), followed by Korycany sandstones (Kk) towards the nappe, which are followed by Cretaceous marls (Kb) of the Bělohorská Formation. Several tectonic faults can be found in the area, mainly in the form of several transverse fractures, along which the rock is considerably fragmented and which have significantly different properties than the intact material in the surrounding area. Three basic underground aquifers can be found in the area.

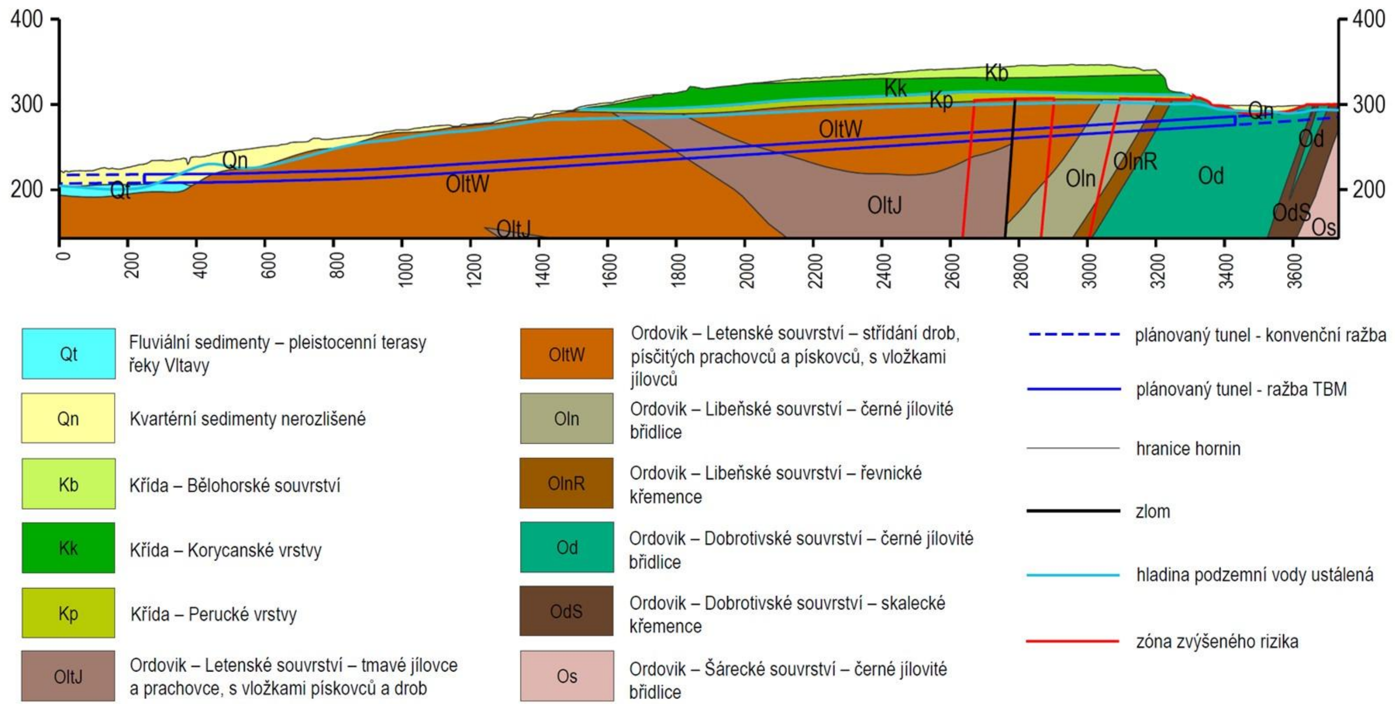

Figure 3: Geological cross-section of the SOUTH variant generated from the 3D geological model of the Czech Geological Survey (Aue et al., 2020), available online

5. THE DESIGNED UNDERGROUNS CONSTRUCTIONS

The tunnel consists of two 3.150 km long single-track tunnel tubes excavated by a full-profile tunnel boring machine (TBM), connections between the main tubes, and a ventilation shaft. The single-track tunnels are circular with an internal diameter of 8.7 m, including a 30 cm safety margin, which also covers construction tolerances (Fig. 4). The lining is designed from reinforced concrete segments containing polypropylene fibers to increase fire safety.

Six cross-passages will be built with a cover ranging from 41 to 84 m above the top of the rail. The ventilation shaft in Střešovice helps to ventilate the single-track tunnels in case of fire.

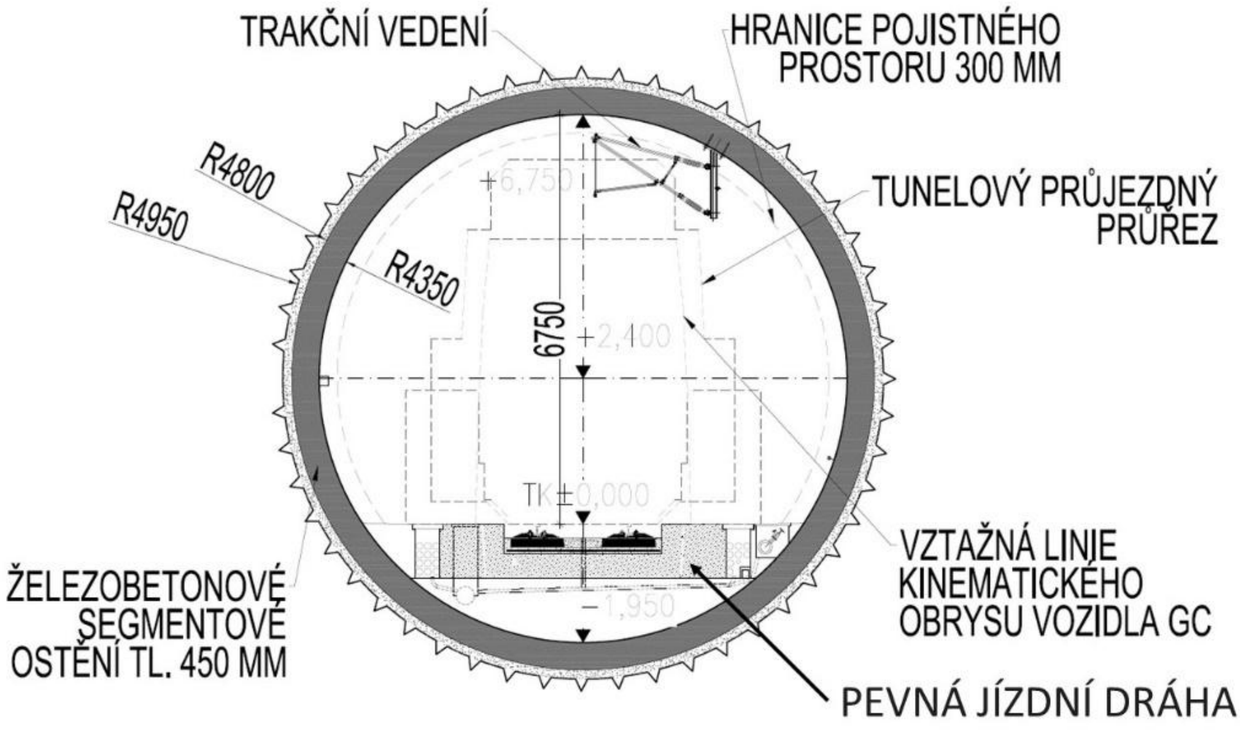

Figure 4: Sample cross-section of a TBM tunnel.

5.1 TBM TUNNELS

Considering the anticipated geological and geotechnical conditions and given that there are no extensive areas of fine-grained soil along the tunnel route, the use of an EPB-TBM is recommended based on DAUB recommendations. The EPB-TBM allows for excavation in three modes depending on the current geological conditions (closed, open, and semi-closed modes). The use of all three modes is predicted along the tunnel route.

The thickness of the reinforced concrete segment lining is currently set at 45 cm, with the possibility of refinement in further design phases. The decisive load conditions for the lining design are in the area of eolian sediments and at the site of tectonic faults between sound shales. In addition, high hydrostatic pressure on the lining is expected in areas of tectonic faults and in the Veleslavín area.

6. RAŽBA POD RAMPOU V ULICI SVATOVÍTSKÁ

TBM excavation will begin from the eastern portal (near the Praha-Dejvice station). This section of the route is located in Quaternary sediments. The TBM must first pass under Svatovítská Street with overburden up to a height of 17 m. This is followed by the excavation of a critical section under the "Svatovítská" access ramp, which brings road traffic into the Blanka city ring road tunnel (see Fig. 5).

The ramp consists of two structures. The first part consists of L-shaped retaining walls in the open part of the roadway. The second part consists of underground walls with a backfilled ceiling slab and a freely laid bottom slab (Milan method). The estimated distance between the foot of the underground wall and the perimeter of the excavated tunnel is only 2.1 m. The ceiling slab resting on the underground walls is loaded with up to 5 m of soil in the overburden. The tunnel foundation slab is connected to the underground wall by a shear key, which is a very sensitive detail of the structure, as it is not designed to transfer significant forces.

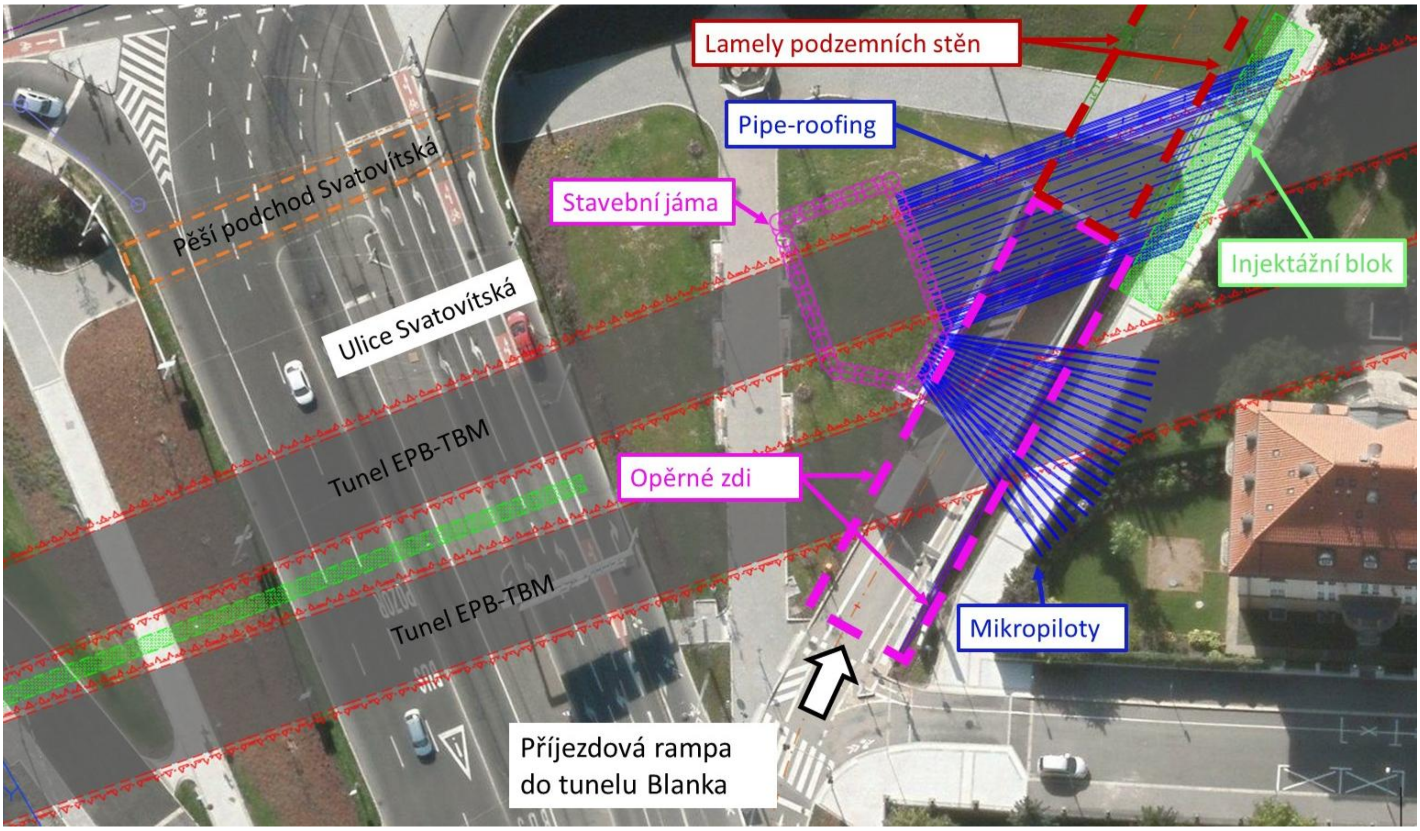

Figure 5: Situation of proposed additional safety measures in the area of Svatovítská Street

The left tunnel tube passes under the underground walls, while the right tube is located under the cut with retaining walls (see Figure 6). The main problems for the design of the TBM tunnel and mitigation of the impact of construction are the high stresses under the bases of the underground walls, together with the high sensitivity of the underground walls to vertical deformation during excavation. For this reason, the designer considered several solutions to mitigate the risks.

Grouting under the footings of the underground walls was considered, but the problem was the access to perform the grouting in sufficient quality and the resulting bearing capacity of the earth block. For this reason, the designer proposes to use the pipe roofing method - to install steel pipes with a diameter of approx. 1.3 m under the underground walls from a temporary construction pit (Fig. 7). Since there is no extraction shaft at the other end of the ramp, the pipes must be installed using an M-TBM retraction machine, and on the other side, the pipe roofing pipes must be supported in the grouting block. The conventional tunnel is then excavated under the protection of pipe-roofing and, together with the temporary shaft, filled with low-strength concrete. This then allows the safe passage of the left EPB-TBM tube in open mode.

A double-row micropile umbrella (micropiles) constructed from a temporary shaft is designed for the space under the L-shaped retaining walls. This fan of micropiles allows the pressure created by the EPB-TBM at the face to be distributed for stabilization. Therefore, the right tunnel tube must be constructed in closed mode under the retaining wall. However, the excavation does not require significant fluctuations in the support pressure at the EPB-TBM face due to the undercut.

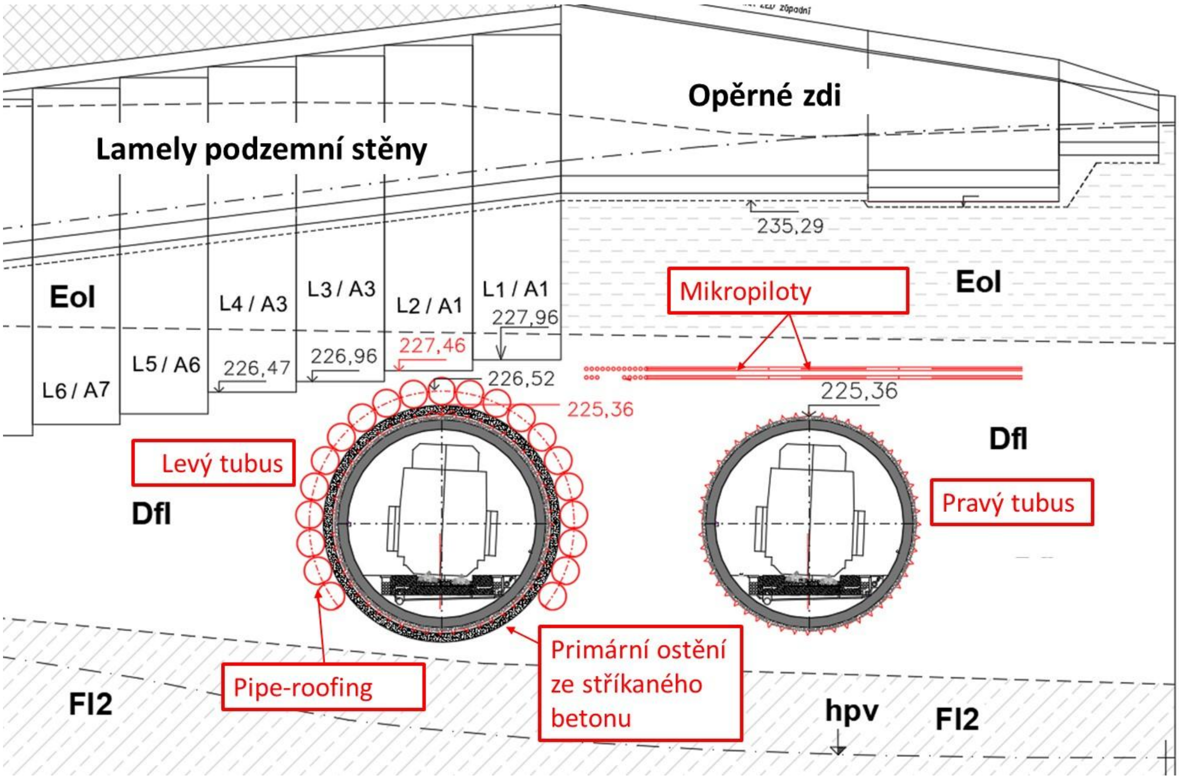

Figure 6: Cross-section of additional measures in the area of Svatovítská Street together with the results of deformations determined by a numerical model (Eol – eolian sediments, Dfl – deluviofluvial sediments, Fl2 – fluvial sediments)

6.1 INSTALATION OF PIPE-ROOFING

Two methods can be used for pipe roofing (installation of steel pipes): jacking and microtunneling. In the case of microtunneling, a bentonite shield (M-TBM) is most commonly used. The choice of this solution is determined by the following factors:

1) tight tolerances when laying steel pipes;
2) the possible occurrence of soil and rock in the excavated cross-section;
3) the requirement for minimal deformation of the surrounding terrain during installation;
4) the possible foundation of underground walls deeper than anticipated, with the risk of collision between the pipes and the bases of the underground walls;
5) impossibility of constructing a pull-out shaft for the arrival of the M-TBM on the opposite side of Svatovítská Street.

Figure 7: Pipe-roofing using AVN 1200 in the Gongbei road tunnel in China (Herrenknecht AG archive)

Only slurry M-TBM meets the above conditions. Due to the impossibility of constructing a construction pit on the opposite side of the Svatovítská ramp, the use of a retractable M-TBM is proposed. This technique allows the M-TBM to be pulled back into the construction pit from which it was pushed out via installed pipes. This is made possible by one of two cutting head systems (see Figure 8). In both cases, the M-TBM leaves its outer steel shell in the rock mass.

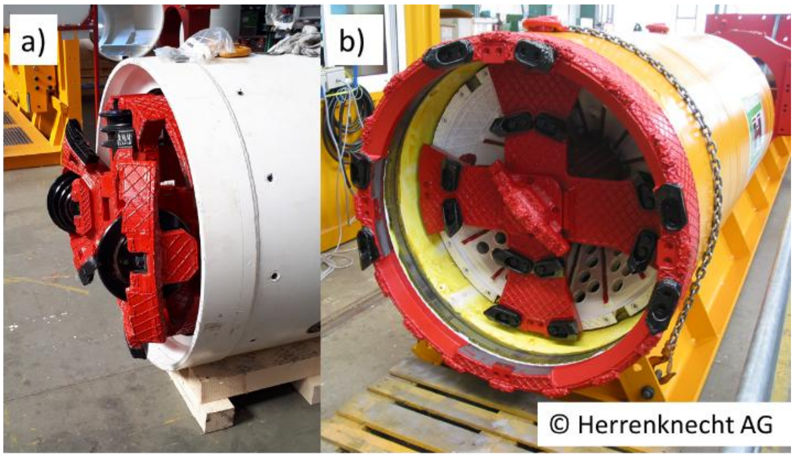

Figure 8: a) First option for the retraction mechanism of the M-TBM machine with a tiltable cutting head b) Second option for the retraction of the M-TBM machine with a lost outer head ring (Herrenknecht AG archive)

7. CONCLUSIONS

The history of this project shows how important it is to have a high-quality, fast building permit system and a consistent source of funding for large infrastructure projects. Public perception of urban planning and the impact of construction on the environment during implementation changes over time.

The SOUTH variant selected by the designer and subsequently rectified to SOUTH-ÚVN was also confirmed by opposing opinions (Thewes et al., 2024; Brož et al., 2020; Aue et al., 2024) as the most suitable route for the tunnels under Střešovice. This variant is optimal, particularly in terms of minimizing the impact on residents both during construction and operation. The opposing opinions provided the investor with recommendations for the next stages of preparation. The results of the reviews are also applicable to other planned transport projects. The designer is now finalizing the technical design of the Střešovice tunnels in the SOUTH-ÚVN variant in detail for the zoning decision documentation. An environmental impact assessment (EIA) is also currently underway, which will be followed by an application for a joint building permit under the Linear Act. The investor expects that the independent assessments will increase public acceptance of the tunnel solution and speed up the EIA process and the obtaining of a joint permit.

The article considers a relatively innovative method of implementing stabilization measures for the Svatovítská ramp underpass, which will require special attention in the next phase of the project.

LITERATURE

- AUE, M. et al. (2024) Zhodnocení navržených variant nového propojení železničních stanic Praha-Dejvice a Praha-Veleslavín ve vztahu ke geologické stavbě zájmového území reprezentované vytvořeným koncepčním 3D geologickým modelem. Česká geologická služba, dostupné na https://geology.maps.arcgis.com/home/webscene/viewer.html?webscene=99cc8742052947c6bef0c087cbe11e65
- BEDNAŘÍK, K. (2020) Porovnání variant. Metroprojekt Praha a.s.
- BROŽ, M. (2020) Nezávislý posudek vlivu vibrací na zástavbu nad železničním tunelem Praha-Dejvice – Praha-Veleslavín.
- DAUB Recommendation for selection of tunnel boring machines (2010) (DAUB = Deutsche Ausschuss für Unterirdisches Bauen e.v.)
- DRAGOUN, F. et al. (2024) Předběžný geotechnický průzkum pro „Modernizace trati Praha-Výstaviště (mimo) – Praha-Veleslavín (mimo)“ – část Geotechnický průzkum ražených tunelů Střešovice. . SUDOP PRAHA a.s.

- CHMELAŘ, R. et al. (2019) Předběžný geotechnický průzkum pro „Modernizace trati Praha-Výstaviště (mimo) – Praha-Veleslavín (mimo)“ – část Geotechnický průzkum ražených tunelů Střešovice. PUDIS a.s.
- THEWES, M. et al. (2024) Expert assessment – Assessment of Alignment Variants

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