PREPARATION OF THE STŘÍŽKOV TUNNEL AS PART OF THE PODŘIPSKO HIGH-SPEED RAIL LINE

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ABSTRACT: The article deals with the preparation of the Prague–Lovosice high-speed line, known as the Podřipsko high-speed line. The first part of the article focuses on describing the entire Podřipsko line. The second part of the article focuses on presenting the concept of the Střížkov tunnel, which is part of the aforementioned high-speed line.

1. INTRODUCTION

The preparation of high-speed rail lines (HSR) in our country has progressed significantly. High-speed lines will become part of the Fast Connections network in the Czech Republic. Fast Connections are defined by the Railway Administration as an operational and infrastructural system of fast railways in the Czech Republic. Fast connections will include not only HSR, but also some lines modified for speeds of up to 200 km/h. The following HSR sections are currently in various stages of project preparation:

- RS 1 HSR Prague – Brno – Ostrava (length 385 km)
- RS 2 HSR Brno – Břeclav (length 44 km)
- RS 4 HSR Prague – Ústí nad Labem – Dresden (length 137 km)
- RS 5 HSR Prague – Hradec Králové/Pardubice – Wrocław (length 273 km)

The RS 4 route connects Prague and Dresden, passing under the Ore Mountains through a very long base tunnel. Our company, Metroprojekt Praha a.s., is at the forefront of 22 design companies that are currently preparing project documentation for RS 4, specifically its Podřipsko section, at the zoning decision project stage (Fig. 1). The name Podřipsko refers to the section of the line between the Prague junction Balabenka and the existing 4th railway corridor, which it connects to between Roudnice and Lovosice. In the future, the RS 4 route should also include another long base tunnel passing under the České Středohoří mountains and ending in Ústí nad Labem.

The first part of this article describes the status of preparations for the high-speed rail line and the general concept of high-speed rail. The second part focuses on the Střížkov Tunnel, which is proposed at the beginning of the high-speed rail route under the Prague district of the same name.

2. HSR PODŘIPSKO

This section of the high-speed rail line is named after Říp, the only natural landmark in the vicinity of the line that has significance beyond the region.

The double-track section begins in Prague and ends with a junction to conventional line No. 090 (known as the “left bank”) outside the town of Roudnice nad Labem. The route of this HSR begins in the wider center of Prague. The project also includes a proposal for the Balabenka junction (Fig. 2), which is one of Prague's complex railway junctions. It connects five large Prague stations, and while today several tracks intertwine on two levels, after the reconstruction, the number of tracks will approximately double and a third level will be added. All this will be coordinated in great detail with the city's ring road, which will run in tunnels under the tracks. The reason for such a generous solution is not the high-speed rail line itself and its connection to Prague, but mainly the need to accommodate the traffic predicted by the Prague Railway Junction study. This junction should be largely completed in the middle of the 21st century, and the Balabenka junction will be one of the first structures directly connected to it. The RS 4 tracks run through this junction from Prague Main Station, where this high-speed rail line will terminate, and at the northern end of the junction they descend into the slope below the Prague districts of Prosek and Střížkov. The tunnels, which are approximately 3,160 m long, are named after the latter.

Figure 1: Overview of the HSR Podřipsko situation

After exiting the tunnels, the track runs through fields between the Letňany and Ďáblice districts, which have great potential for future development. The Prague Institute of Planning and Development (IPR) is planning a completely new urban district here. For this reason, the IPR is also requesting the establishment of a railway station. The station should be built parallel to Cínovecká Street (the continuation of the D8 motorway in Prague), and because its full potential will only be realized with possible new development in the vicinity of the station, it is proposed to be built in stages. The expansion of the initially temporary Praha Sever station into a full-fledged station should be possible while the line remains in full operation.

Figure 2: The new Balabenka track layout

In the section beyond Praha Sever station, trains will exceed the speed of conventional railways. Up to the area north of the village of Líbeznice, the design speed is 250 km/h, and the track first crosses the planned outer Prague D0 motorway ring road (specifically the D520 section) via a 90 m long bridge, before diving underground again. The 3,400 m long double-track Líbeznice tunnel will take the HSR through the relatively densely built-up area north of Prague. Beyond its northern portal, trains will be able to accelerate to the planned speed of 320 km/h, or a prospective 350 km/h. It is here that the route leaves Prague and continues through the Central Bohemian Region, running almost directly alongside the D8 motorway to the Ústí Region. The last major transport hub on this section, with the working name ŽST Roudnice n/L HSR, is located on the border between the Central Bohemian and Ústí Regions.

Before describing the transport hub itself, it is necessary to mention several artificial structures that precede it. The first of these could be a tunnel bridge, referred to as an overpass for legislative reasons, but with a width of 99 m. It is an ecoduct, but its purpose is not to create a migration route for wildlife, but to connect two nearby parts of a nature reserve (PR Vršky pod Špičákem). Another structure is the 900 m long Úžice flyover, under which a road and railway line No. 092 pass. Behind the village of Zlosyň, the line is designed in close coordination with a planned large gravel and sand quarry, and immediately behind it is the longest flyover on RS 4, the 1,600 m long Vltava flyover. Its length is mainly determined by the wide strip of active floodplain of the Vltava River at this location. It crosses the river itself via a 25-meter-high bridge with a span of 80 meters. Immediately behind this flyover, there is a proposed space reserve for a junction where the Poohří high-speed rail line will connect to the city of Most. This is currently being examined in a separate study, and it is not certain whether it will proceed to the next phase of preparation. The last major artificial structure in the Central Bohemian Region is the Ledčice Tunnel, named after the village it passes under. It is surprising that it was possible to plan almost 50 km of new construction in the study in such a way that the only demolition of residential buildings took place in this village. The HSR will run through a 1,100 m long cut-and-cover tunnel here.

The Roudnice HSR station will form a high-capacity transport hub. Track No. 096 will be connected to the 4-track station, providing a transport link to the town of Roudnice nad Labem. This single-track line will enter the station via a triangle, which will also be used to turn some work trains around before they enter the maintenance base. A significant part of the maintenance of the entire future RS 4 will be carried out from this service center, for which its own trackage and halls are being designed. Maintenance will take place regularly at night when passenger train traffic on the high-speed line is interrupted.

The remaining part of the HSR route consists of another 10 km of track on two flyovers several hundred meters long, of which about one-third will be HSR parameters. At the Kněždol junction, the HSR will branch off to the conventional line No. 090, which will be the only continuation of this line towards the northern border of the Czech Republic for one to two decades. The HSR section through the Středohoří Mountains is not only a technical but also a political challenge, and therefore its implementation is expected to be delayed.

It should be noted that, in addition to classic 2D documentation, a BIM model containing non-graphical information is also being created for the entire route in accordance with the requirements of the Railway Administration for the DÚR stage. The public can follow the progress of the preparations on the GIS portal https://vrtky.cz/podripsko .

2.1 TUNNELS AT HSR PODŘIPSKO

In addition to the aforementioned Střížkovský tunnel, there are two other tunnels on the Podřipsko HSR route. Specifically, these are the Ledčičcký tunnel and the Líbeznický tunnel. The Ledčičcký tunnel is entirely constructed in an open pit, while the Líbeznický tunnel is partially designed to be constructed using the cut-and-cover method and partially excavated. While the design of the Střížkovský tunnel is being carried out by Metroprojekt, the remaining two tunnels are being designed by colleagues from Sagasta s.r.o.

The tunnels are primarily designed according to the "Manual for the Design of High-Speed Railways at the DÚR Stage" published by the Railway Administration based on shared know-how with the French railways (SNCF).

2.1.1 Tunnel Líbeznice

The new double-track cut-and-cover tunnel is designed to be 3,400 m long. The design speed is 250 km/h. From the entrance portal for the first 140 m, the tunnel is being constructed in an open construction pit. The next 600 m is being constructed using the NATM method (Fig. 3). The remaining 2,660 m of the tunnel will again be constructed as a cut-and-cover tunnel in an open construction pit. Due to the location of the tunnel outside the built-up area and mostly at a shallow depth below the surface, a sloped construction pit is proposed. The tunnel structure will be backfilled to the level of the current terrain with a layer at least 1 m thick.

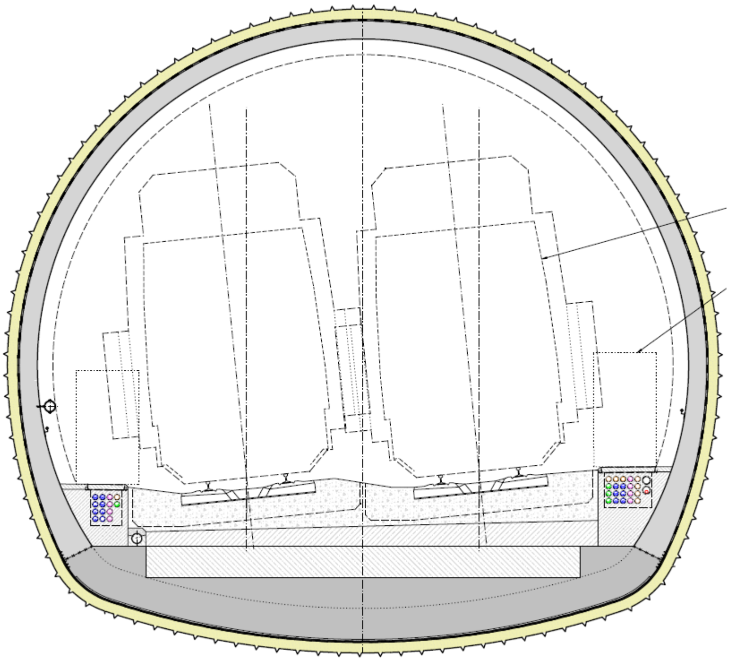

Figure 3: Cross-section of the excavated part of the Líbeznice Tunnel (Sagasta s.r.o.)

The tunnel grade follows a valley curve, which required the design of a pumping sump. The tunnel lining is designed from reinforced concrete to be waterproof with sealed joints using internal sealing strips. The dimensions of the tunnel's clear profile comply with the HSR Design Manual. The clear profile of the tunnel is 91.8 m2 (for a design speed of 230 to 270 km/h, the requirement is a minimum of 90 m2). The vault is based on a foundation slab, the thickness of which depends on the encountered geology and the height of the backfill. Thicknesses of 800 and 1200 mm are proposed.

Excavation will be carried out according to the principles of the New Austrian Tunneling Method. Due to the length of the tunnel, three escape structures are proposed (maximum distance is 1000 m). Emergency response areas and technological structures are proposed on the surface near the escape structures. The tunnel crosses eight roads, ranging from second-class roads to pedestrian walkways.

2.1.2 Tunnel Ledčice

The new double-track cut-and-cover tunnel has a proposed length of 1,450 m. The design speed is 320 km/h. The entire length of the tunnel will be cut-and-cover (Fig. 4). Due to the location of the tunnel, which is mostly outside the built-up area, and its shallow depth, a sloped construction pit with a maximum of three slope levels separated by benches is proposed.

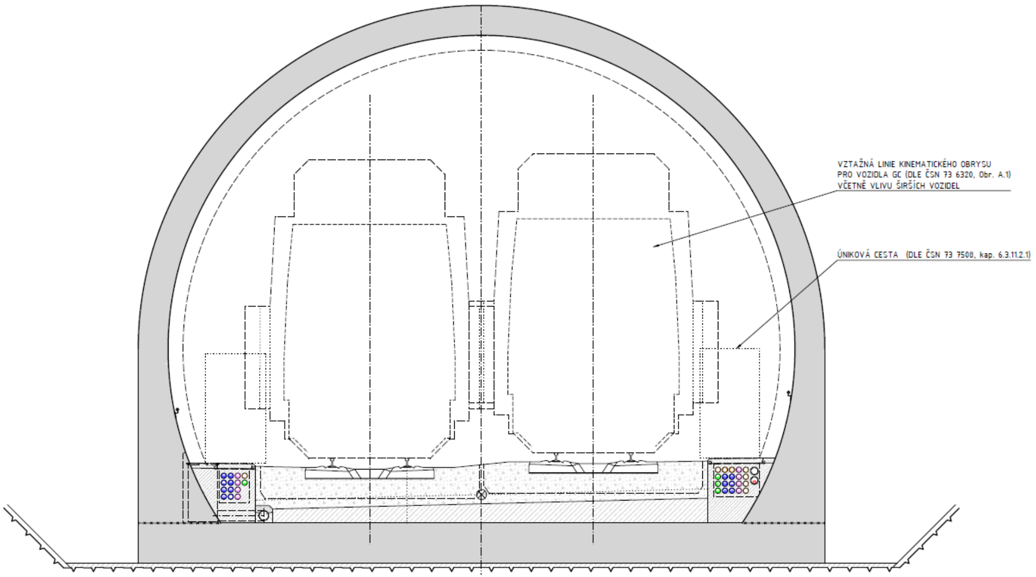

Figure 4: Cross-section of the Ledčice Tunnel (Sagasta s.r.o.)

The tunnel axis runs along a directional curve with a maximum track superelevation of 150 mm. The tunnel has a roof-like longitudinal slope, with the grade rising from the entrance portal and then falling. The dimensions of the tunnel's clear profile comply with the Manual for High-Speed Rail Design (the inner face of the lining is a circle with a radius of 6.5 m). The clear profile of the tunnel is 99.6 m2 (for a design speed of 270 to 350 km/h, the recommendation is a minimum of 100 m2). The level of the sidewalk edge is again designed to be at the height of the top of the adjacent rail. The tunnel crosses several field roads and third-class roads.

3. STŘÍŽKOVSKÝ TUNNEL

The Střížkovský Tunnel complex (Fig. 5) consists of two single-track bored track tubes (Fig. 6), a cut-and-cover portal section at Balabenka, a cut-and-cover portal section at Letňany (Fig. 7), and excavated cross-passages. The left and right single-track bored tunnels have a total length of approx. 3,160 m, of which approx. 3,000 m will be bored using an EPB-TBM full-profile tunnel boring machine (Fig. 6). The tunnel grade rises from the entrance portal at a gradient of 16.5‰. Due to the maximum longitudinal slope of the tracks, the tubes are routed at different heights within the directional curves. This required the installation of stairs in the cross-passages.

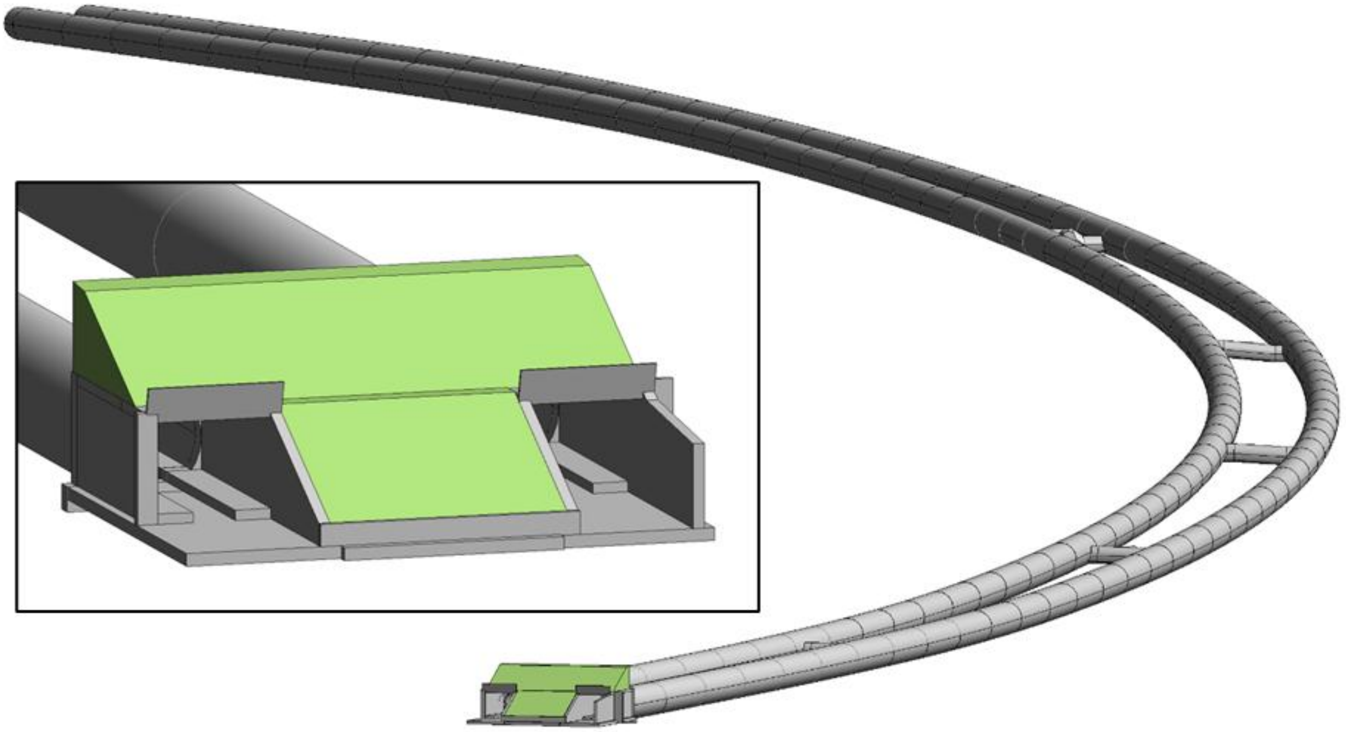

Figure 5: BIM model of the Střížkov Tunnel

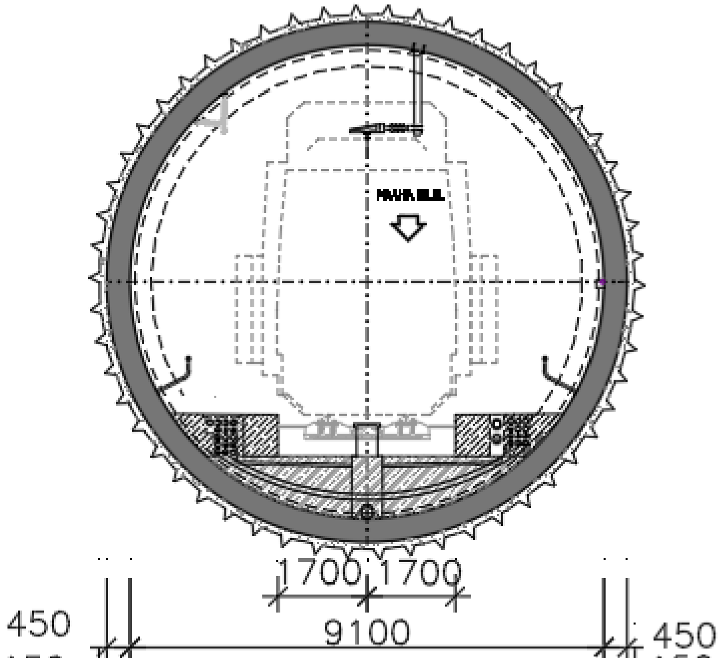

Figure 6: Cross-section of the excavated part of the Střížkov Tunnel

The design speed in the tunnel is considered to be up to 200 km/h. Given this, it is not an HSR tunnel. For this reason, its cross-section was not designed according to the HSR manual, but according to the Railway Administration's model sheets for tunnels with speeds up to 200 km/h. However, reducing the cross-section compared to the HSR manual required the installation of a fixed catenary for aerodynamic reasons.

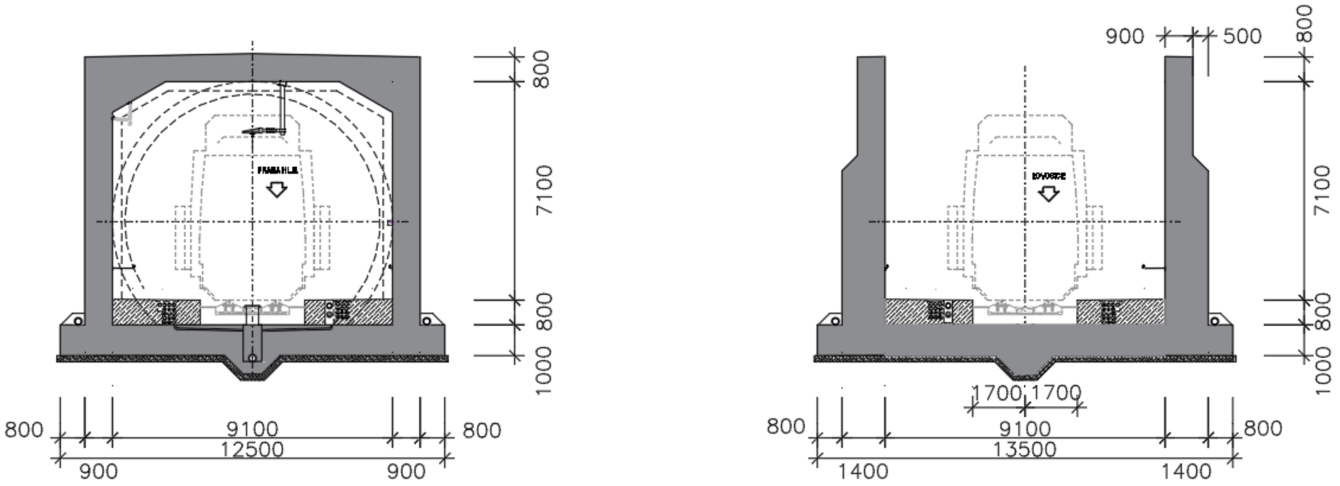

Figure 7: Cross-section of the excavated part of the Střížkov Tunnel

3.1 GEOTECHNICAL CONDITIONS

The section between km 5.660 and 6.170 passes through rocks of the Letná Formation, and conditions here are similar to those at the entrance portal. Clayey-silty shales with quartzite layers are present. Rock strength increases with depth. The tunnel profile will mainly contain shale with a strength corresponding to class R4, while more weathered shale of class R5 will be found in the initial section around the tunnel portal and in the overburden. Quartzite deposits represent very resistant rock, which will cause higher wear on the cutting shield. According to laboratory analyses, the strength of quartzite in simple compression averages 40 MPa. During drilling work, RQD values of predominantly 0, max. approx. 50%, were documented.

The section km 6.170-6.280 passes through a fault zone at the foot of the Prosecká plateau. The tectonic line runs through the area in the WWN-EES direction and caused the formation of a depression filled with Quaternary sediments overlying the underlying Ordovician rocks. Quaternary deluvial and deluviofluvial sediments of a clayey and sandy loam nature with a variable proportion of underlying rock fragments can be assumed. The pre-Quaternary bedrock consists of Ordovician rocks of the Letná Formation, characterized by monotonous clayey-silty shales of black-gray color, which are weathered to greater depths due to tectonic lines. The immediate overburden of the tunnel will consist of completely weathered shales of a clayey soil with a firm consistency. During drilling, RQD values of 40-90% were predominantly documented.

The section between km 6.280 and approx. 7.660 passes through clayey-silty shales belonging to the fine-grained (pelitic facies) development of the Letná Formation or Libeň Formation. The tunnel grade rises and the overburden thickness ranges from a maximum of 62 m at km 6.540 to 36 m at km 7.660. The tunnel will be excavated mainly in sound clayey and clayey-silty shales. The rocks have a compressive strength at the lower limit of class R3, most often corresponding to a range of approx. 18-34 MPa. The presence of quartzite layers is rare. The distance between discontinuities is small to medium; RQD in the range of 30-80% was most often documented in exploratory boreholes.

The section between approximately km 7.660 and approximately km 7.900 passes through a tunnel at the boundary between two completely different lithological units of Lower Cretaceous and Ordovician rocks. The tunnel grade rises and the overburden thickness ranges from 36 to 29 m. In the upper part of the tunnel profile, sandstones of the Korycany Formation begin to appear, which are weakly diagenetically consolidated and correspond to class R5-R4. The sandstones are fine to coarse-grained and broke down into fragments and sand during drilling. The RQD corresponds to a value of 0 in almost the entire sandstone profile. A layer of claystones belonging to the Peruc layers is usually present in the bedrock beneath the sandstones. The claystones are gray to black-gray in color and contain organic residues, or are even coal claystones. The rock is not very strong and the fragments can be crushed by hand; their deformation is partially plastic. This layer, if present, is usually about 0.5-1.5 m thick. The transition to Ordovician rocks can be sharp or may include a transitional layer of weathered rocks. The dark gray Libeň clay shales were laterally weathered in the upper layer to a depth of about 2.0 m.

Groundwater is found mainly in Cretaceous sandstones, which form a significant aquifer, while the claystones at the interface between the layers and the underlying shales are practically impermeable. With the increasing proportion of sandstones in the tunnel profile, groundwater inflows will increase significantly.

The section between approximately km 7.900 and approximately km 8.757 passes through a tunnel with a full profile of chalk sandstone from the Korycany layers. The thickness of the overburden gradually decreases from 29 m to 9 m at the northern portal of the excavated section. The sandstones are weakly diagenetically consolidated and correspond to class R5-R4. The Cretaceous sandstones again form the main aquifer for groundwater in the area, and due to the impermeable bedrock, water accumulates on the chalk base. The rocks are weakly to moderately fractured and form a moderately to strongly permeable aquifer.

3.2 CHOICE OF TECHNICAL SOLUTION

First, it was necessary to select the most suitable tunneling technology and the associated track solution. The options considered were a double-track tunnel excavated using NRTM technology or two single-track tubes excavated using the TBM method. The primary criterion evaluated for these two options was the speed of construction, with the option of two single-track tunnels excavated using TBM clearly dominating. The option of two single-track tunnels also offers a higher level of operational safety and, last but not least, a suitable location for the tunnel's technological equipment in the tunnel connections. The choice of the TBM excavation option is supported by the possibility of establishing a high-quality logistics base in Letňany for excavation services.

Static calculations have shown that, given the geological conditions encountered, it is necessary to use a machine capable of actively supporting the tunnel face with backfill pressure. Based on preliminary geotechnical surveys, the requirements for tunneling technology can only be determined approximately. There are three types of full-profile TBMs with active tunnel face support. In addition to the earth pressure balance (EPB) shield, there is a bentonite shield and a variable density shield. Due to the absence of extensive areas of soil without fine particles in the proposed tunnel route, an EPB-TBM earth pressure balance shield is proposed. The advantage of this type of machine over the other two types is its lower price and operating costs. The EPB-TBM also allows excavation in three modes depending on the current geological conditions (closed, open, and semi-closed modes). All three modes are likely to be used during the excavation of the Střížkov tunnel.

Due to relatively unfavorable geological and hydrogeological conditions in terms of excavation stability, a significant part of the tunnel will have to be excavated in closed mode. This is the only way to minimize surface settlement and minimize the impact on the hydrogeological situation in the area of interest. Open mode excavation will only be used in sound rock with minimal groundwater permeability through fissures. A semi-closed mode is proposed for the transition between the closed mode and open mode excavation areas. Groundwater inflows into the tunnel will be regulated by closed mode TBM excavation in areas with high inflows.

The required tunnel cross-section was determined based on a design speed of up to 200 km/h from the SAMPLE SHEET OF CLEAR TUNNEL CROSS-SECTIONS OF A SINGLE-TRACK TUNNEL Appendix 12 Mechanized excavation – Geometry – from 161 km/h to 230 km/h fixed track, superelevation 0 - 160 mm (without offset). The tunnel lining is designed as a prefabricated concrete lining Φ 9.1/10.0 m thick, 450 mm with wire reinforcement or conventional steel reinforcement. The concrete strength class must be at least C35/45 and must not exceed C50/60 due to the brittleness of the concrete. More detailed requirements for concrete quality are not specified at this stage of the project documentation.

For the purposes of project preparation, the resulting excavation diameter is considered to be Φ 10.3 m. The considered excavation is 150 mm larger on each side than the outer edge of the segmental lining. The size of 150 mm is given as indicative at the current stage of documentation. This space is technologically necessary, among other things, for machine control. At the end of the rear envelope of the shield, pressure grouting is then performed, e.g., using two-component grouting. The tolerance for the directional and height guidance of the excavation is considered to be 100 mm on each side of the tunnel axis. These 100 mm for the excavation tolerance are allocated outside the 300 mm safety space.

The segmental lining of railway tunnels is sealed against water in transverse and longitudinal joints using elastomeric seals. These elastomeric seals can be equipped with bentonite tapes, which swell on contact with water and further seal the area. The elastomeric seal has been proven to meet the tightness requirements for twice the required hydrostatic pressure, taking into account the degradation of the seal during the design life of the lining and the mutual rotation of the segments or mutual displacement of the rings. The watertightness requirement is the design value of the water column height after 100 years.

The rail solution for the tunnel envisages a fixed track design with a maximum track gradient of 60 mm. The specific type of fixed track is not specified at this stage of the design. Compared to a fixed track, the use of a ballast bed would require an increase in the tunnel diameter for two reasons:

1. by 0.2 m in diameter. While maintaining the existing tunnel diameter, the use of a ballast bed would reduce the width of the escape route to 1022 mm. According to PBŘ, sidewalks must be at least 1.1 m wide. Increasing the excavation by 0.2 m would increase the theoretical excavation area from 83.3 m^2 to 86.6 m^2.
2. by 0.7 m due to the placement of drainage cleaning shafts in the walkways for accessibility reasons and to maintain the possibility of mechanical cleaning of the track bed.

The use of SLAB TRACK in the single-track Střížkov tunnel is therefore more economical in terms of excavation area and segment lining area. This comparison is based on the need to place the edge of the sidewalks up to 2.26 m from the track axis according to the sample sheets. This distance allows for mechanical cleaning of the track bed and also its effective maintenance in terms of track rectification due to the use of the same mechanisms as on an open track. In the case of SLAB TRACK, the need for maintenance is minimized, but compared to a ballast bed, higher investment costs for the railway superstructure itself must be taken into account, ranging from 20 to 40% (data from German literature). SLAB TRACK also allows for the placement of a damping mass-spring system that prevents the spread of vibrations into the tunnel surroundings. In contrast, a ballast bed only allows for the installation of damping mats between the ballast and the reinforced concrete structure in the tunnel, which is less effective. The position of the escape walkway above the TK is 0 mm on the left side of the tunnel. On the right side, the walkway is located at the level of the crown of the adjacent elevated rail. The Střížkov Tunnel is unique in its design.

Rescue niches will not generally be built in this type of lining. An exception and interesting feature of the Střížkov tunnel is a niche for a filter that will block DC currents (DC filter). The reason for the location of this filter is a change in the type of traction power supply in front of the tunnel near the portal at Balabenka. The construction of this recess is designed as a connection stub.

The TBM track tunnels are connected to the portal section tunnels (Fig. 8), which are constructed as excavated open construction pits. While in the Letňany area the length of this section is approximately 140 m, at Balabenka the planned length of the excavated section is only about 20 m. This is due to the steeper slope of the overburden at Balabenka, as TBM excavation requires a certain minimum overburden.

As part of the comparison of variants, the use of one TBM complex or two TBM complexes, which would excavate both tubes of the Střížkov tunnel simultaneously, was assessed. Given the length of the tunnel, the designer opted for the use of only one TBM complex in order to save money and reduce the length of the tunnel. In the case of using two TBM complexes, the construction time would be reduced by only about 12 months, which would not be significant in terms of the time required for other sections of the HSR line.

Two options were examined in terms of the excavation procedure for the Střížkov Tunnel:

1. Excavation from the portal at Balabenka towards Letňany – top excavation
2. Excavation from Letňany towards the portal at Balabenka – downward excavation

In terms of the possibility of locating the construction site, supplying the construction site, and its impact on the surrounding area, the option of tunneling from Letňany towards Balabenka is clearly the winner. The Letňany area also allows for the establishment of comfortable construction site facilities, together with a segment lining factory and a concrete plant. This concrete plant will also be used for other structures built as part of the HSR.

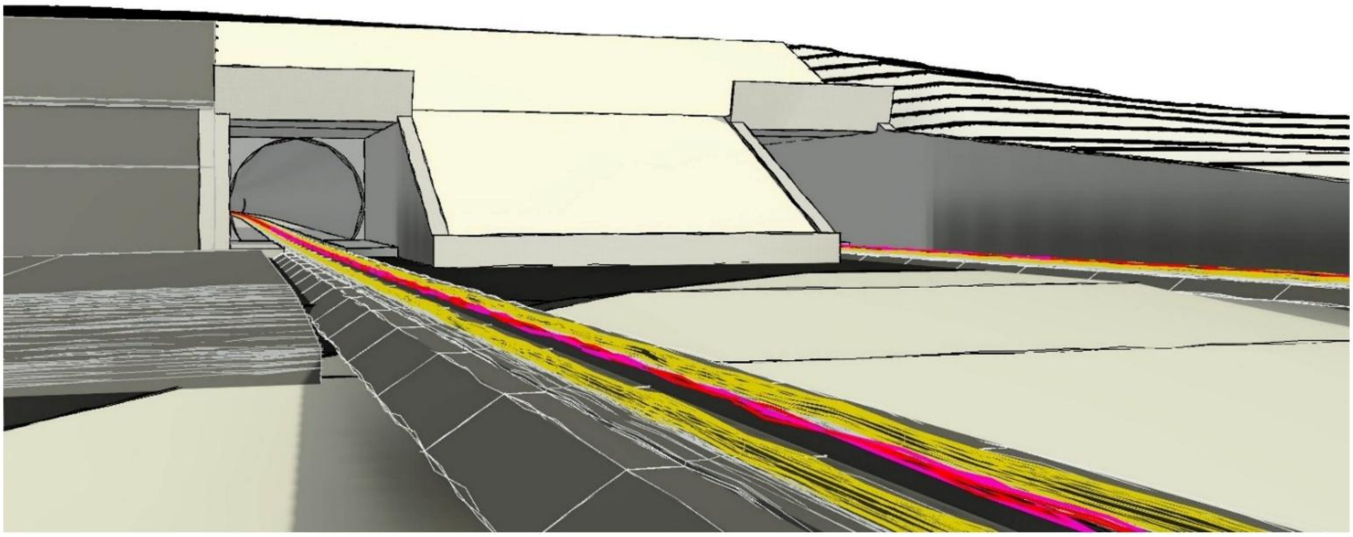

Figure 8: Visualization of the Střížkov Tunnel portal at Balabenka (architect Pavel Sýs)

3.3 CROSS-PASSAGES

The need for tunnel cross-passages (Fig. 9) is based on the TSI, which is referred to by the tunnel safety rules when defining the necessity of cross-passages. The connecting tunnels are designed as NRTM excavated tunnels. The design generally assumes a maximum spacing of 450 m between connections, which is documented in the PBŘ as sufficient based on the evacuation and smoke models. Locally, this distance may be reduced due to above-ground buildings so that the connection tunnel is not excavated under sensitive above-ground buildings. Seven connection tunnels with overburden ranging from 15 m to 59 m are designed for this section.

As mentioned earlier in the article, the height of the two tracks deviates along the tunnel route. In the case of a small height difference between the track tunnels, the cross-passages run directly (longitudinal slope of the cross-passages up to 1:8 = 12.5%). At higher slopes, a staircase is placed in the cross-passage to compensate for the slope.
Three types of cross-passages:

- Basic with side branches – In connecting tunnels No. 2 and No. 4, a tunnel perpendicular to the connecting tunnel will always be built to accommodate additional technological equipment. In connections No. 5 and 6, two side tunnels will be built. Two perpendicular tunnels will be built for the placement of additional technological rooms. These additional rooms will be accessed via side branches from the main tunnel of the connection. Connections No. 5 and 6 will contain stairs to overcome the height differences between the track tunnel tubes. Behind the pressure-tight doors of the connection (in the protected area) in front of the stairs themselves, there is always a barrier-free area with a minimum area of 30 m2.
- Enlarged without side branches - Connections No. 1, No. 2, and No. 7 do not have a side tunnel, but they have an enlarged basic cross-section so that the escape tunnel next to the technical rooms meets the TSI conditions (width 1.5 x height 2.25 m).

The connections will be excavated after the construction of the track tunnels. After ensuring the stability of the finished segment lining at the penetration points and removing the relevant parts of the reinforced concrete prefabricated lining, the relevant connections will be excavated using NRTM technology and fitted with primary lining. Subsequently, a waterproofing layer will be laid and the secondary lining will be concreted.

The monolithic reinforced concrete structures in the excavated connections are provided with a foil coating insulation made of softened PVC resistant to pressure groundwater on the reverse side. The entrances to the connections will be equipped with two pressure-tight doors. The ventilation equipment allows for the extraction of excess pressure in the connections.

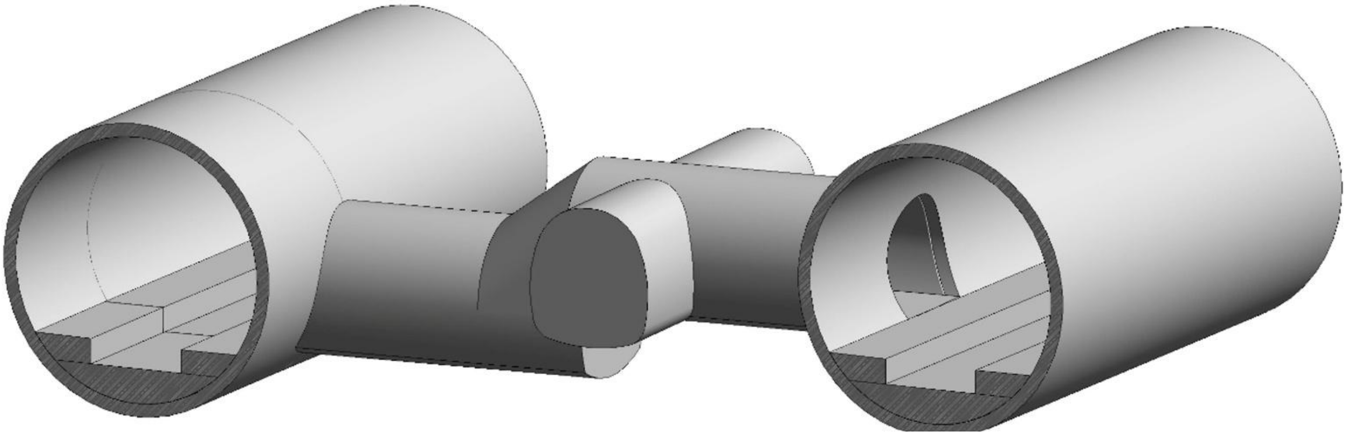

Figure 9: Střížkovský tunnel connection with cross-cut and different elevations of track tunnels

4. CONCLUSION

There is still a lot of work ahead for the designers before the actual implementation of the RS 4 section. This includes conducting a detailed geological survey and subsequently refining the tunneling mechanism and tunnel equipment, as well as completing the technological design projects. A key task for the designers is to explain the selected HSR solution to the public and demonstrate that the landscape and population will be affected by the construction of the HSR to the smallest possible and acceptable extent.

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