# CURRENT STATUS OF THE DETAILED GEOTECHNICAL INVESTIGATION FOR THE BEROUN TUNNEL

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ABSTRACT: The construction of the new Praha-Smíchov – Beroun railway line is part of the III Transit Railway Corridor in the Praha – Plzeň – Cheb (– Nürnberg) section. The most significant part of the new line is the Beroun Tunnel, which, at a length of nearly 25 km, intersects the morphologically prominent area between the Vltava valley in Hlubočepy and the Berounka valley in Beroun. This tunnel, currently the longest designed tunnel in the Czech Republic, passes through the geologically and structurally highly complex territory of the Central Bohemian Barrandien. For this project, an extensive detailed geotechnical investigation was launched in 2023, carried out by the "Beroun GTC+SG" association (GeoTec-GS, a.s., SG Geotechnika a.s.). This paper discusses the current status and partial available results after the completion of Stage I of the geological investigation. The geotechnical investigation for such a significant structure consists of a set of various types of investigation works and numerous methods aimed at providing a comprehensive view of the engineering-geological, hydrogeological, and geotechnical conditions along the tunnel route and related structures. Technical works of the detailed investigation primarily include exploratory boreholes with depths reaching over 200 meters in some places. These boreholes allow for dilatometer and water pressure tests, a complex set of logging methods, and the installation of pore pressure gauges at the level of the projected tunnel excavation. Technical works are supplemented by laboratory soil and rock mechanics tests, including a set of specialized technological tests. Furthermore, a geophysical survey is being conducted to clarify the geological structure and detect significant tectonic faults, along with a hydrogeological survey focused on verifying the hydrogeological properties of the rock environment, fault zones, and assessing the impact on groundwater resources in the area of interest.

## 1. INTRODUCTION

The Praha-Smíchov – Beroun line section is part of the III Railway Corridor Praha – Plzeň – Cheb (– Nürnberg). Increasing the capacity of the existing track led through the Berounka valley is practically impossible due to the landscape morphology, nature protection requirements, and significant urban development of the area. For these reasons, the Praha-Smíchov – Beroun section was designed in a completely new route, with the Beroun Tunnel forming the majority of this section. The main purpose of the proposed underground work is to enable the railway line to overcome the morphologically prominent area between the Vltava and Berounka valleys, where elevations near the villages of Vysoký Újezd and Svatý Jan pod Skalou reach up to 440 m a.s.l. (Herinky Hill near the Záhrabská settlement), while the river valleys are at approximately 195–215 m a.s.l.

The proposed tunnel starts at km 7.112 at the Hlubočepy portal near the Barrandov Bridge and continues southwest toward Slivenec. Here, a branch of the tunnel from the Praha-Krč station joins the main route, starting at a portal near the Braník Bridge in Malá Chuchle. In the Slivenec area, the main route turns west toward the village of Ořech and continues through Zbuzany, Tachlovice, and Vysoký Újezd. After Vysoký Újezd, from approximately km 22.5, the route heads southwest toward the village of Svatý Jan pod Skalou, where it crosses the deep valley of the Loděnice stream at approximately km 28.300. The tunnel then continues southwest to the Záhrabská settlement and ends at km 31.749 at the Beroun portal in the Beroun – Závodí district. The tunnel is followed by a viaduct over the Berounka River heading directly into the Beroun railway station, where the planned Praha-Smíchov – Beroun section ends (Fig. 1).

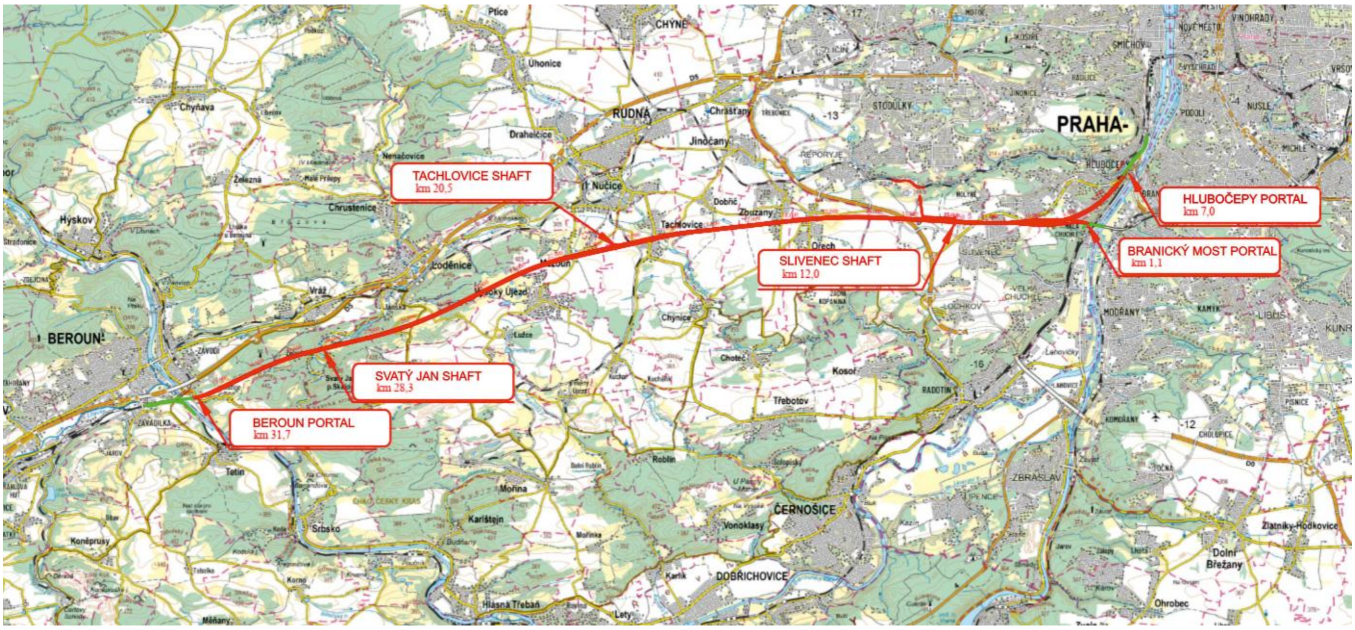


Figure 1: Overview situation of the Beroun Tunnel route with marking of individual objects

The tunnel is designed as two single-track driven tunnels with a fixed track and a design speed of 200 km/h; both tunnel tubes are regularly connected by cross-passages. The total length of the main route is 24.758 km (for the left track tunnel), and the length of the Braník branch is 2.037 km (for the right track tunnel). The tunnel route is divided into several sections separated by caverns with permanent access shafts; some sections will be excavated conventionally (NATM), while others will use a Tunnel Boring Machine (TBM). The excavation diameter of the track tunnels will be approximately 10.5–11.5 m depending on the excavation technology, but it reaches up to 21 m in the sections of caverns and track branching. Initial tunnel sections from the Hlubočepy and Braník Bridge portals to the Slivenec cavern will be excavated conventionally (NATM), as will the Slivenec, Tachlovice, and Sv. Jan caverns. The track tunnel sections between the Slivenec and Tachlovice caverns (km 12.01–19.73), Tachlovice and Sv. Jan (km 21.16–28.29), and Sv. Jan – Beroun portal (km 21.16–31.73) will be driven by TBM. The overburden height along the tunnel route is usually 110–130 m; it is lowest in the portal sections and at the crossing of the Loděnice valley in Sv. Jan pod Skalou (km 28.386), where it is only 25 m. The maximum overburden thickness is about 1.3 km further toward Beroun near the Záhrabská settlement (km 29.675), reaching up to 185 m.

## 2. GEOLOGICAL CONDITIONS ALONG THE TUNNEL ROUTE

From a geological perspective, the tunnel route passes through the Lower Paleozoic region (Chlupáč I., 1992), forming the central part of the Barrandien in Central Bohemia. Paleozoic rocks lie discordantly on

Cadomian-folded Proterozoic rocks. The part of the Barrandien in the section between Prague and Beroun represents the core of the Prague Basin, which consists of a sequence of Ordovician to Middle Devonian sediments and volcanics. The rocks were then folded by the Variscan orogeny into a system of simple anticlines and synclines disturbed by transverse and longitudinal fault tectonics (Havlíček et al., 1986). The folded Paleozoic rocks are partially covered by platform sediments of the Upper Cretaceous. This region is among the most diverse areas in the Czech Rebublic, but i tis also one of the most complex from a structural geology perspective.

The tunnel route passes along the northwestern flank of the Central Bohemian Silurian-Devonian synclinorium; its direction is parallel to the axis of the Holyně-Hostim syncline (Fig. 2). The entire complex of Paleozoic sedimentary and volcanic rocks is folded with a general direction of fold axes ENE – WSW. In the section from Hlubočepy to Slivenec (approx. km 12.0), the route passes through the southeastern flank of the syncline with a layer dip of approx. 50–60° to the NW. In the Slivenec area, the route crosses the syncline axis, after which the dip azimuth turns to the SE. In the section from km 12.0 to Beroun, the route passes through the northwestern flank of the syncline, with the layer dip reaching mostly 30–50° to the SE to SSE. The folded rock complex was subsequently affected by longitudinal fault tectonics, with the most significant structure in the area being the Tachlovice overthrust with a dip of 50–80° and a displacement in the order of hundreds of meters (Fig. 3). In the final tectonic phase, the entire area was affected by a large number of transverse faults with a predominant NW-SE or NNW-SSE direction and a dip of (70–90°). Transverse faults lead to significant vertical and horizontal displacements of rock structures.

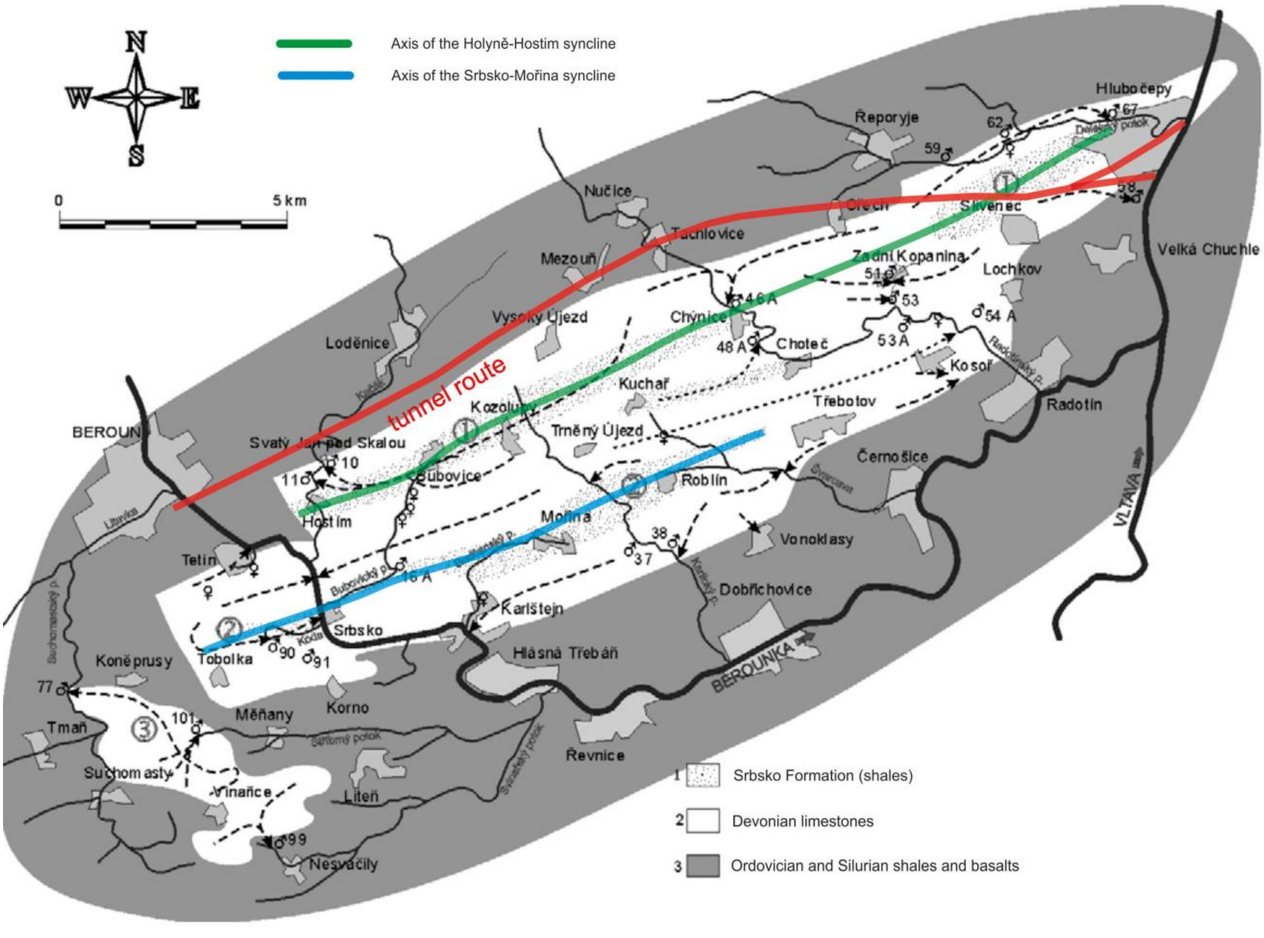


Figure 2: Orientation of the tunnel relative to the main geological structures, including the representation of major hydrogeological bodies and assumed flow directions in the main aquifer, according to Bruthans and Zeman 2001, supplemented with the tunnel route and axes of the main synclines.

The complex of folded Paleozoic rocks is represented in the tunnel route by rocks of Ordovician, Silurian, and Devonian age; given the tunnel's length, a diverse range of rock types was encountered during the investigation. The oldest sediments belong to the Upper Ordovician and occur only locally around Zbuzany, Tachlovice, and Lištice near Beroun. They consist of silty shales and siltstones with layers of light gray sandstones and quartzites of the Kosov Formation; clayey shales of the Králův Dvůr Formation were occasionally encountered. Silurian rocks form the largest part of the tunnel route and occur in a nearly continuous belt between the village of Ořech and Beroun. All Silurian formations were encountered, but the dominant portion of the route consists of rocks from the Motol Formation (Lower Silurian). These are black silty graptolite shales, tuffaceous shales, and limestones supplemented by thick layers of volcanic rocks (basalts, hyaloclastites, and tuffs). Upper Silurian rocks (Kopanina and Požáry Formations) occur locally at the beginning of the route in the Prague Barrandov area and around Řeporyje and Vysoký Újezd, predominantly having the character of silty and calcareous shales and limestones with bodies of basalts and hyaloclastites. The proportion of limestones increases significantly, especially in the youngest Požáry Formation.

Figure 3: Encountering the Tachlovice overthrust in borehole J30, depth section 40–47 m. In the hanging wall of the fault zone are older shales and quartzites of the Kosov Formation (Ordovician), while younger shales and basalts of the Motol Formation (Silurian) were encountered in the footwall.

Devonian sediments form the central part of the syncline and occur at the beginning of the route in the section from Hlubočepy to Řeporyje. The Lower Devonian is represented in the route by the Lochkov, Praha, and Daleje-Třebotov Formations; Middle Devonian rocks belong to the Choteč and Srbsko Formations. Most Devonian rocks are represented by various types of limestones (stratified, nodular, or massive micritic limestones). An exception is the Daleje layers, formed by calcareous shales with a subsequent transition into Třebotov limestones. The final phase of sedimentation in the Prague Basin is represented by the Srbsko Formation, consisting of a thick layer of silty to clayey shales and siltstones with layers of fine-grained sandstones (Roblín layers). Paleozoic limestones are often affected by karst phenomena, primarily the Devonian limestones of the Lochkov and Praha Formations. Karstification was also occasionally described in the Choteč limestones and Silurian limestones of the Kopanina and Přídolí Formations. Karst phenomena in this area have the character of so-called paleokarst—karst formed under different hydrological conditions than today. Typical for the Bohemian Karst are irregular labyrinthine cavities linked mainly to fractures, bedding, or fault planes and easily karstifying limestone layers. Another significant phenomenon is karst phenomena that affected the original surface of Devonian limestones (deep depressions and karst canyons). These were filled and completely covered during sedimentation in the Upper Cretaceous period.

Paleozoic rocks are partially covered by platform sediments of the Upper Cretaceous; a continuous cover was found between Prague's Barrandov and Ořech, with local occurrences recorded near Zbuzany and Vysoký Újezd. The rocks belong to the Peruc-Korycany Formation, consisting of alternating weakly consolidated sandstones and claystones. In the Slivenec area, a unique occurrence of claystones and marlstones of the Bílá Hora Formation was found, with a typical layer of glauconitic sandstones at the base. The thickness of Cretaceous sediments usually ranges between 10–25 m, but in karst depressions, Cretaceous sediments were encountered in thicknesses exceeding 100 m. Quaternary cover along the tunnel route is represented mainly by eolian and deluvial soils, with fluvial sediments occurring to a small extent. The total thickness of Quaternary soils usually ranges from 0.5–4 m, occasionally reaching up to 12 m (deluvial debris at the foot of high slopes).

From a hydrogeological perspective, a main groundwater aquifer can be defined in the Paleozoic rocks, formed by the Devonian "limestone" formations of Lochkov and Praha, and limitedly by the overlying Zlíchov Formation. Choteč limestones represent a local aquifer. The overlying Devonian aquitard consists of shales of the Daleje-Třebotov Formation and, in particular, shales and siltstones of the Srbsko Formation (Roblín layers). The underlying aquitard is represented by Silurian shales, tuffs, and basalts of the Liteň group, or Upper Ordovician shales.

## 3. SCOPE OF INVESTIGATION WORKS

The scope of implemented works was specified by the bidding documentation for the geotechnical investigation (BUCEK, R.; NEŠVARA, P. 2023). According to this documentation, the investigation was divided into four separate parts:

- Investigation for shafts;
- Investigation for portals and other surface structures;
- Engineering-geological and hydrogeological investigation for the tunnel;
- Geophysical investigation for the tunnel route.

In terms of the volume of assigned work and the time schedule, the detailed geotechnical investigation (GTI) is divided into several consecutive stages. The scope of the investigation is updated during the execution of field works in accordance with the requirements of the investor and designer, and with regard to continuously obtained information about the character of the rock environment.

Figure 4: Execution of exploratory borehole J1 in the serpentines of Barrandovská Street in Prague (June 2024).

The GTI bidding documentation proposed a set of engineering-geological boreholes and equipped hydrogeological boreholes, supplemented by field tests and borehole logging, laboratory tests, and geophysical investigation. Hydrogeological investigation was also an integral part of the exploratory works. The aim is to clarify the engineering-geological and hydrogeological conditions in the area of interest and to verify the geotechnical conditions for the design and excavation of the tunnel.

For the tunnel object, including access shafts and portal areas, a total of 105 exploratory boreholes (98 vertical and 7 inclined) with a total footage of approx. 11,800 m are proposed within two basic GTI stages; the depth of boreholes (outside portal sections) reaches 57–203 m. In soils and highly weathered rocks, a simple core barrel with a TCI bit is generally used for drilling. In solid rocks, wire-line technology with a double core barrel and diamond bits of PQ (122 mm) and HQ (96 mm) diameters using water flush is subsequently utilized. From a level of 5 m above the tunnel crown, NQ diameter (76 mm) is used, primarily due to the requirement for geotechnical tests in the tunnel excavation area. Subsequently, borehole logging is performed—a complex of geotechnical methods supplemented by an acoustic/optical scanner (ABI/OBI). These measurements allowed for the determination of selected geological and geotechnical characteristics, including the orientation and dip of discontinuities and the determination of natural groundwater flow in the borehole.

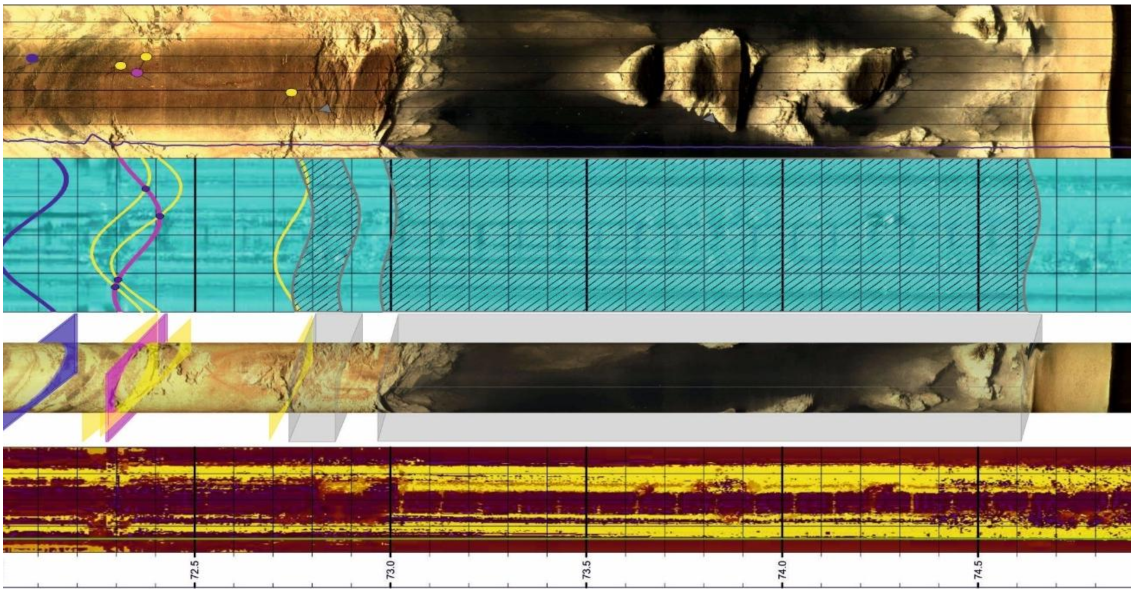


Figure 5: Karst cavern in borehole J7 at Barrandov, depth 73–75 m (excerpt from logging record), interface of Slivenec and Radotín limestones, Devonian.

As part of the field test set, pressuremeter or dilatometer tests were performed in the boreholes. Given the occurrence of mostly healthy rocks in the excavation area, a dilatometer probe was primarily used for testing. To verify the permeability of the rock mass or encountered fault zones, water pressure tests were assigned. In tunnel boreholes, tests were implemented in the excavation area; in boreholes for access shafts, they were performed continuously throughout the entire length of the borehole. Subsequently, the boreholes were equipped with pore pressure sensors and the borehole stem was sealed with a clay-cement suspension. The goal is long-term monitoring of groundwater pressure at the excavation level before tunnel construction, during construction, and after its completion to evaluate the influence of the construction and operation of the work on the surrounding rock environment.

For the tunnel object, including shafts and portals, an extensive set of soil and rock samples was assigned by the GTI project, especially from the excavation level, including a set of large-volume technological rock samples and mixed samples for environmental purposes. Classification analyses and determination of deformation and shear parameters were performed on soil samples; for samples from the filling of fault zones, the clay mineral content was determined using the RTG method. On rock samples, physical properties, unconfined compressive strength, tensile strength and deformation parameters, and petrographic descriptions of rocks were determined. A significant part of the rock testing consisted of a set of special tests for the design of the TBM method, some of which were introduced in the Czech

Republic and used for the first time in accordance with international methodology during this investigation. These include rock abrasivity tests—the CERCHAR method, so-called "Norwegian tests"—determination of DRI and CLI indices, LCPC tests (abrasiveness and grindability tests), and determination of equivalent quartz content. These tests were supplemented by the Slake durability test (disintegration in water) and the rock slurry formation ability test. To potentially use the tunnel muck for aggregate production, the rocks were assessed for strength, water absorption, and alkali-reactivity; for limestone rocks, the CaO content was determined (for use as a raw material for cement production).

In Stage I, the hydrogeological investigation for the tunnel focused on the passportization of water resources, boreholes for heat pumps, and monitoring boreholes in a belt along the tunnel route, and on chemical analyses of groundwater samples. In Stage II, a total of 18 equipped hydrogeological boreholes with depths of 30–186 m and a total footage of approx. 2230 m are currently proposed. Borehole logging in the full range of hydrogeological methods and long-term hydrodynamic tests will be performed to assess the hydrogeological properties of the rock mass and verify the reach of the possible influence on hydrogeological conditions by the implementation and subsequent operation of the tunnel.

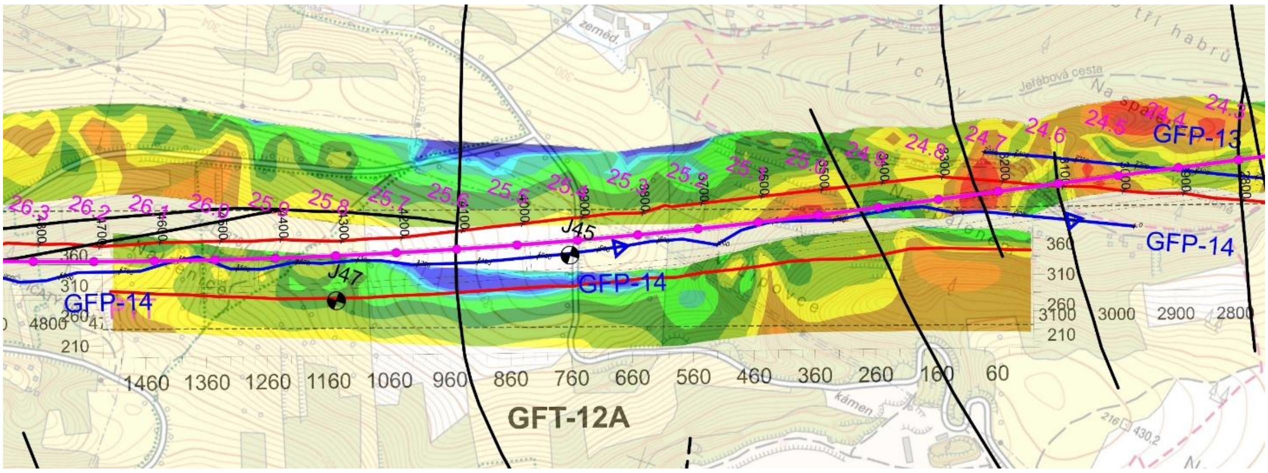


Figure 6: Fault zone with a width of at least 700 m (stationing approx. km 25.1 – 25.8) encountered by geophysical investigation in the valley south of Loděnice. The fault zone is manifested by a significant decrease in resistivity (blue and light green colors).

The goal of the geophysical investigation was to provide a continuous image of the lithological structure between individual boreholes and to locate prominent tectonic lines and fault zones where deteriorated rock mass quality with higher groundwater inflows can be expected. Regarding the depth of the tunnel, geoelectric methods electrical resistivity tomography (ERT), dipole resistivity profiling (DRP) and time domain electromagnetic method (TDEM)] were primarily used; in the location of shallow shafts and access adits, they were supplemented by shallow seismic refraction (SSR). The ERT and TDEM methods were situated in the route profile led by the longitudinal axis of the tunnel and in transverse profiles at the shaft locations. A total of 27 partial ERT profiles with a total length of 42,270 m and 240 TDEM probes were measured. To clarify the spatial orientation of tectonic lines, 20 partial profiles using the DRP method with a total length of 26,360 m were performed in parallel with the ERT profiles. Five transverse profiles with a total length of 4800 m were measured using the SSR method.

## 4. EVALUATION OF STAGE I RESULTS OF THE DETAILED GTI

Stage I exploratory works began in September 2023 and were completed in January 2026. During this stage, approximately 50% of the total volume of work for the tunnel itself was implemented, and the geophysical investigation was completed in its full scope. Based on the interim GTI results for the tunnel route, some important pieces of information were identified that will influence the tunnel design at this phase of project work.

- The geological conditions verified by the newly drilled boreholes correspond from a broader perspective to the assumptions about the structure of the area of interest between Prague and Beroun. On a more detailed scale, however, the geological structure is significantly more complex both in terms of the number of rock types encountered and their alternation, and in terms of the tectonic disturbance of the mass. Information about the geological and tectonic structure will be supplemented and refined based on the evaluation of Stage II works.

- In the section from the Hlubočepy portal to the Slivenec cavern (section km 7.1–9.5), karst caverns were encountered in Devonian limestones. These are karst channels and cavities often linked to fractures, bedding, or fault planes and rock interfaces. The cavities have sizes in the range of several meters, are partially or completely filled with sediments, and locally contain groundwater circulation. In several boreholes, cavities with strong water inflow were verified at the projected level of the tunnel excavation.
- The surface of Devonian limestones was affected in the geological past by intense karstification, creating deep valleys that were subsequently filled and completely covered by younger Cretaceous sediments. These consist mainly of decomposed to weakly consolidated claystones and sandstones, which are generally water-bearing. These valleys were verified in several places by boreholes and geophysical investigation. At Prague's Barrandov, the karst valley reaches a depth of approx. 55 m (12 m above the tunnel excavation). An extensive karst depression was encountered between Barrandov and Slivenec at the site of the planned track branching (stationing km 9.6–10.2). According to current information, the Cretaceous canyon, including the completely karstified bedrock, reaches a depth of at least 130 m and extends to the excavation level (in this section at a depth of 118–140 m). Based on this information, the designer is considering moving the tunnel branching and the subsequent cavern to a more suitable location toward the village of Slivenec. The depth and aerial extent of the Cretaceous canyon will be verified in Stage II of the investigation, for which 4 exploratory boreholes were placed in this location.
- South of the village of Loděnice, in the section km 25.1–25.8, the tunnel passes through a prominent fault zone. According to information from resistivity sections, the fault is oriented transversely to the tunnel axis. Subsequently, this fault zone was verified by exploratory boreholes J45 and J47. Over a length of approx. 700 m, we expect the occurrence of highly altered and crushed rocks extending below the excavation level.
- At several locations, groundwater overflow above the ground level was encountered. This includes borehole J45 in the aforementioned fault zone area near Loděnice, where logging detected a significant inflow above the excavation level (depth approx. 70 m) with an artesian head of approx. 0.2 m above the ground. Deeper inflows could not be verified due to unstable borehole walls in altered rocks. Water overflow was also encountered in borehole J29 near Tachlovice. Here, a significant groundwater inflow was found in Ordovician shales and sandstones at the base of the excavation (depth approx. 92 m) with an artesian head of 1 m above the ground. This is highly mineralized water of the Na-Cl type (so-called brine) with an increased concentration of dissolved methane. The occurrence of groundwater containing methane cannot be ruled out in the vicinity of the Slivenec shaft as well. In the Beroun portal area, one of the sub-horizontal boreholes showed a more significant water overflow from a sharply defined tectonic structure, which was grouted during the works. Investigation works in Stage II were operatively targeted to verify the described issues.
- In the portal section at Hlubočepy, the investigation identified open and debris-filled sub-vertical tectonic faults. Given their depth reach into the excavation space, their parallel orientation to the longitudinal axis of the tunnel, and the low overburden, the work technology will be modified at this location.
- Hydrostatic water pressure measured in the excavation area reaches values of 1000–1600 kPa in some boreholes, which are higher values than anticipated. During the works, the reliability of the measured pressure values from some boreholes was addressed regarding the minimum permeability of the rock environment determined by water pressure tests. Regardless of this fact, water pressure values above 1000 kPa are confirmed along the route in boreholes where pore pressure sensors are installed in locations with proven groundwater inflow. The issue of

high-water pressures and measurement reliability will need to be further addressed in subsequent investigation stages.

## 5. CONCLUSION

This paper discusses the partial results of Stage I of the detailed geotechnical investigation for the Beroun Tunnel, which is currently the longest designed tunnel in the Czech Republic. The introductory part summarizes information about the technical solution of the work, the description of the planned tunnel route, and the projected scope of investigation works.

The first stage of the detailed geotechnical investigation confirmed that the construction of the Beroun Tunnel will take place in a geologically diverse and structurally very complex area. Thanks to information from exploratory boreholes and geophysical measurements, it was possible to identify critical spots, such as the Cretaceous canyon at Slivenec or the extensive fault zone at Loděnice. No less significant is the probable presence of high hydrostatic pressures in the excavation area and the occurrence of highly mineralized waters with methane content, which may influence the design of the tunnel lining. Concurrently, special tests of technological properties and rock abrasivity were introduced in the Czech Republic for the first time, providing key data for the future configuration and effective deployment of TBMs. The investigation also verified the presence of karst cavities with water inflows at the excavation level, which will need to be taken into account during the planned conventional excavation in these sections. Ongoing monitoring of water resources supplemented by hydrodynamic tests in Stage II will allow for predicting the construction's impact on the groundwater regime.

Stage II of the GTI, currently underway as this paper is written, is focused on obtaining more detailed information about the engineering-geological and hydrogeological conditions along the tunnel route. Simultaneously, emphasis is placed on refining and supplementing the findings identified in Stage I.

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