

NEW CHALLENGE FOR THE PRAGUE METRO – CONSTRUCTION OF THE PANKRÁC D SINGLE-VAULT TRANSFER STATION

Václav Anděl

Subterra a.s., Prague, Czech Republic

Štefan Ivor

Subterra a.s., Prague, Czech Republic

ABSTRACT: The Pankrác D metro station in Prague is a single-vault transfer station with side platforms. It will be the largest station on the entire D line and will hold three firsts within the Prague metro system: it will be the first transfer station excavated using the NATM method, the first single-vault transfer station, and the first transfer station with side platforms. The station was excavated from two directions, from the PAD1b and VO-OL locations, and the vestibules were excavated from a construction pit in the PAD2 location. The track will be 33 meters below the surface. The article describes the experience of the contractor with the excavation of individual parts of the single-vault Pankrác D station, including all technical measures used. During the excavation of the Pankrác D station, the lowest part of the profile, the so-called base gallery, was excavated first, which was non-standard. Another specific feature was the implementation of extensive chemical grouting through IBO 32 self-drilling steel bolts in order to improve the properties of the rock mass, especially in the so-called Kosovo formation, and to minimise groundwater inflows into the station profile. Another interesting fact is that the excavation is taking place in close proximity to the operational metro C line, close to the Pankrác C station, specifically at a minimum distance of approximately 4 m below it.

1. BRIEF DESCRIPTION OF THE PANKRÁC GEOLOGICAL SITUATION

From a geological point of view, the Pankrác D station crosses the core of a syncline formed by Silurian rocks represented by the Kopanina and Liteň formations, which overlie Ordovician rocks represented by the Kosov formation in the PAD4 section, see Fig. 1. Between the Ordovician and Silurian formations, there is a layer of Paleozoic volcanic rock – diabase.

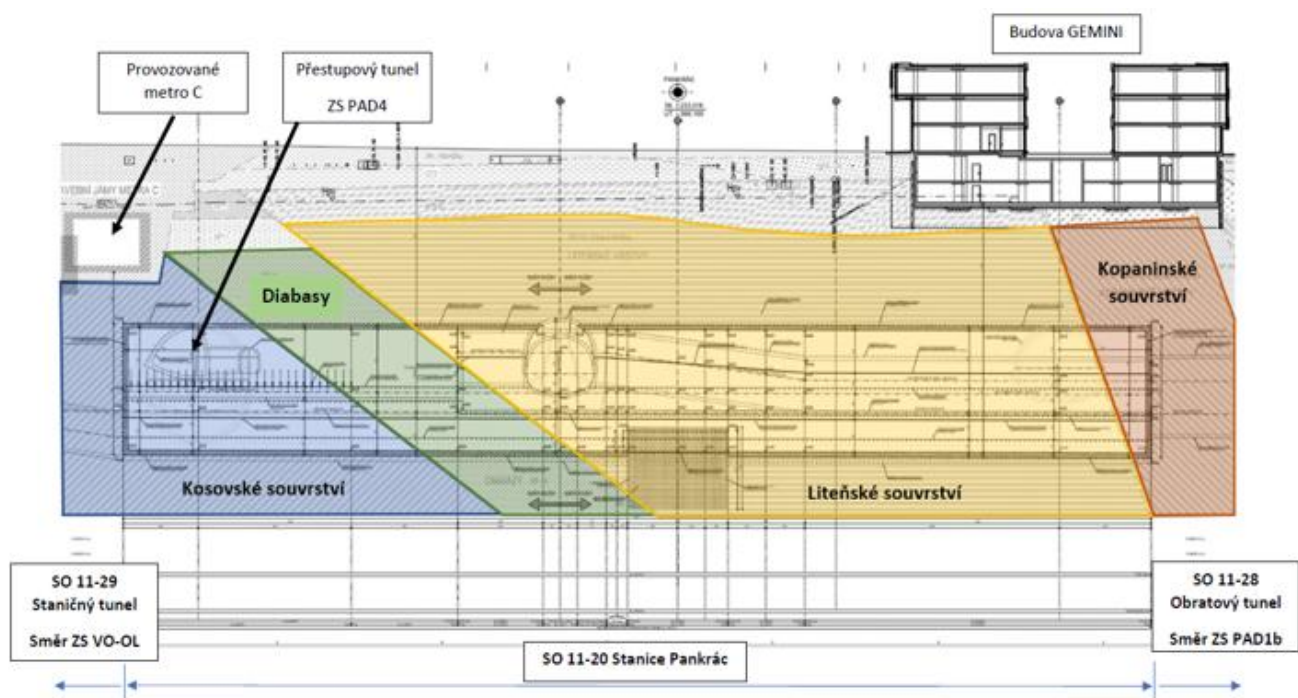


Fig. 1: Longitudinal section of the station with geology

1.1 KOSOV FORMATION

The Kosov layers are the youngest Ordovician formation. It is a flysch formation with rapid alternation of greenish clayey, dusty and sandy thinly layered shales, and plate-like to bench-like jointing quartz sandstones, quartzites, and greywackes. The upper part of the formation is dominated by coarse-grained bench-like sandstones, with no shale intercalations. The total thickness of the formation is around 80–120 m. The rocks are also significantly tectonically disturbed, heavily fractured, and strongly limonitised on the exfoliation surfaces. Due to their flysch character, they are also prone to landslides. Contact with water or air caused rapid degradation of the Kosov shales.

1.2 LITEŇ FORMATION

The Liteň layers are developed as dark grey to black clayey to dusty calcareous shales and contain frequent beds and lenses of very hard limestones in their upper part. Tuffites are also common. The total thickness of the Liteň layers is around 30–80 m. The shales themselves are thinly laminated with very abundant graptolite fauna on the bedding planes. However, the bedding is often almost imperceptible, and fractures are the main areas predisposed to weathering.

1.3 DIABASE

Diabase volcanism is associated with Upper Ordovician and Lower Silurian sediments, involving submarine eruptions of volcanic bodies accompanied by volcanic ejecta, tuffs, and tuffites. Diabase is greenish grey, generally very hard, with a characteristic ophitic structure and spherical or cushion-like separations. It also forms completely irregular, heavily weathered rock formations with clayey decomposition. Diabase mainly forms intersections of bedding veins or extensive lava outflows at various depths of sedimentation, especially at the interface between the Kosov and Liteň or Liteň and Kopaniny layers. However, isolated occurrences have also been documented in the Liteň and Kopaniny layers. Diabase veins here reach a maximum thickness of 10-30 m. Diabase volcanism is accompanied by the sedimentation of tuffs and tuffites. Those are dusty shales mixed with volcanic ash.

2. HYDROGEOLOGICAL CONDITIONS

A discontinuous groundwater table occurs mainly at the base of terraced fluvial sediments at a depth of 6.0–7.0 m below ground level, where the thickness of the aquifer usually does not exceed approximately 1 m. Due to limited natural infiltration of precipitation, the recharge of this horizon is minimal. In rocks, water is bound to the near-surface zone of rock loosening and tectonically disturbed zones. The steady groundwater level in the hydrogeological massif of Ordovician shales (fractured environment) is at a depth of 15–20 m below ground level. During excavation, localised concentrated inflows of groundwater into the tunnel can be expected, especially in areas of tectonic disruption of the massif. Due to the extensive use of chemical pressure grouting, groundwater inflows during the excavation of the Pankrác D station were minimised, and most of them occurred during the drilling of boreholes for the chemical grouting itself and during the drilling of radial bolts during excavation.

3. PROCEDURE FOR THE CONSTRUCTION OF THE PANKRÁC D STATION

Due to its size and accessibility, the Pankrác D station excavation is divided into 11 sub-excavations, see Fig. 2. Due to the anticipated complex geotechnical conditions of the Kosov formation, especially at the point where it crosses the existing Metro C line, the lowest profile, the so-called base gallery, was excavated first, which is unusual. Pressure chemical grouting was then carried out from this gallery in order to reinforce the individual layers in the profile of the future station and approximately 2.5 m above its profile. Subsequently, excavation continued in a standard manner from the upper profiles downwards, first the side sub-excavations, and finally the central sub-excavation with the gradual demolition of temporary internal structures, including the vault of the base gallery. The advantage of this atypical excavation procedure was that when connecting the primary lining of the central sub-excavation, the entire station profile was already closed. Due to the height of the Pankrác D station of

approx. 20 m and the only possible access from vertical shafts, the base gallery was excavated from the shaft at the VO-OL construction site, most of the side excavations from the PAD4 construction site, and the rest of the excavations and demolition of internal structures from the PAD1b construction site. The station excavations were carried out according to the principles of the New Austrian tunnelling method. Due to the size of the profile, the length of an advance was fixed at 1 m so that it was possible to connect the individual partial excavations, primarily their lattice girders. In general, excavation was carried out in technological classes TT5a or TT5b, the main difference being that in class TT5b, chemical pressure grouting through pre-installed spiles was used as part of the excavation, while in TT5a, all rod support elements were simply filled with the same chemical mixture. TT5b was used extensively in areas of the Kosov formation and in tectonically affected areas. The advantage of using a chemical mixture to fill the rod support elements was that, in the event of groundwater drilling, it was possible to immediately perform pressure grouting through these elements and minimise water inflow. During the excavation and installation of lattice girders in all profiles, great emphasis was placed on their most accurate assembly so that they could be subsequently connected. The rock was broken up either mechanically, mainly in the Kosov formation, or in combination with blasting in the diabase, the Liteň formation, and partly when encountering thicker layers of quartz sandstone in the Kosov formation. Blasting was significantly limited by the seismicity of the surrounding buildings, with the maximum charge per time step set at 0.8 or 1.2 kg by the blasting project. The biggest challenge from the point of view of blasting was its use in close proximity to the operated metro C line, as noise limits allowed blasting to be used between 6:00 a.m. and 10:00 p.m. Therefore, it was agreed with the metro operator that the blasting would take place at a time when the metro trains had the longest intervals between runs, i.e. between 9:00 p.m. and 10:00 p.m. After preparing for the blasting work, the metro dispatcher confirmed that the blast could be carried out after the train had departed from the Pankrác C metro station. Subsequently, metro operations staff visually inspected the operated section of the tunnel and allowed another metro train to pass. No extraordinary incidents had to be dealt with during the entire period of blasting work.

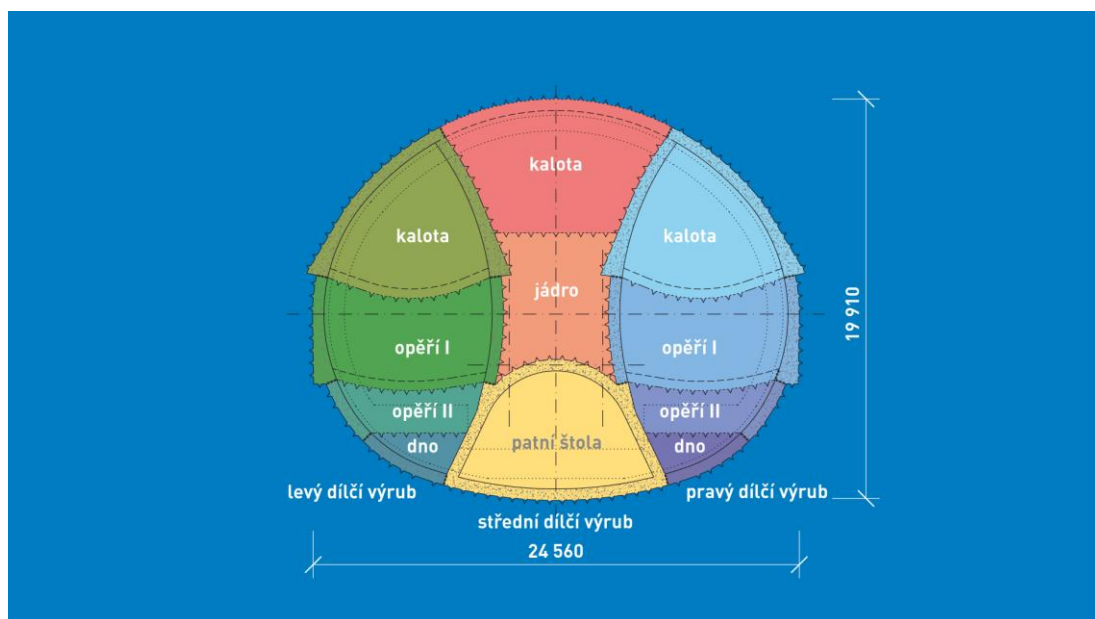


Fig. 2: Sequencing of excavations for station construction

3.1 EXCAVATION OF THE BASE GALLERY

The excavation of the base gallery began in June 2022. In the first phase, the second half of the base gallery profile, approximately 44 m long, was completed; the first half had been excavated as part of the engineering-geological survey. The rest of the base gallery, approx. 86 m, was excavated in full profile, see Fig. 3. The profile size was approx. 52 m² and the primary lining consisted of shotcrete, 2 layers of KARI mesh 8/150x150 mm, additional bar reinforcement of profiles 12, 16, 20 or 25 mm, and atypical reinforcement frames made of steel profiles in the bottom of the base gallery along its entire length and in the vault, mainly in the Kosov formation and near the GEMINI escalator in the Liteň formation. In the

rest, classic lattice girders were used as reinforcement frames in the vault. The thickness of the primary lining was 550 mm. For the driven spiles, radial bolts, and face anchors, 32 mm diameter IBO self-drilling steel bolts in lengths of 6 and 8 m were used. After excavating an advance in the entire profile of the base gallery, the lower part of the reinforcement frame was assembled first, then fixed with shotcrete, and finally the rest of the reinforcement frame was assembled in the vault. The disadvantage of steel frames made of steel sheets was the inability to spray the entire frame. Due to the smaller profile of the base gallery, smaller tunnelling machines were used for excavation, such as the WIMMER Blue Badger or VOLVO ECR235 tunnel excavator and the BERGMAN 815 dumper for excavation. Excavation of the base gallery was completed in February 2023. Work on pressure chemical grouting then began.



Fig. 3: Excavation of the base gallery

3.2 CHEMICAL GROUTING FROM THE BASE GALLERY

Two-component polyurethanes (CarboPur WF, WX) or two-component organic-mineral resins (CarboThix) were used for chemical pressure grouting. In general, organic-mineral resins were used for grouting as part of excavation through driven spiles or face anchors. Polyurethanes were used for grouting outside of excavations, e.g., after the base gallery was excavated. Grouting was performed through steel self-drilling IBO bolts with a diameter of 32 mm and various lengths from approx. 8 m to 22 m through the primary lining of the base gallery. As usual, preparation for the grouting was important, consisting of drawing the locations of individual boreholes and precisely marking each borehole, see Fig. 4. The holes were drilled and then grouted in sections approximately 10 m long, with holes drilled and grouted at intervals of approximately 4 m to minimise clogging of adjacent holes and to allow pressure grouting to be performed through each drilled hole. Depending on the length of the borehole, the maximum grouted pressures ranged from 40 bar to 80 bar. Another important part of the preparation for grouting was the selection of suitable properties of two-component polyurethane materials in terms of their setting time after mixing both components. For short boreholes, the setting time was set at approx. 5 minutes, and for long boreholes at approx. 15-20 minutes. In addition to the maximum pressures, the project specified the maximum amount of grouting material for each borehole – 10 kg per 1 running meter of borehole – in order to minimise the impact of the grouting on the surrounding area. During the grouting process, the surrounding area was monitored and evaluated, and in the event of undesirable effects, especially uplift at the grouting site, the maximum pressures or maximum grout quantities were reduced. Due to the significant amount of injection mixture expected to be consumed, the individual chemical components were stored in IBC containers, which simplified their handling. The injection was initially carried out using GX45 pneumatic pumps, followed by SK90 gear pumps. A total of 20,240 m of boreholes were drilled during pressure grouting from the toe tunnel, and 199,143 kg of two-component polyurethanes were injected. The grouting took approximately 2.5 months.



Fig. 4: Injections from the toe tunnel

3.3 EXCAVATION OF TOP HEADINGS AND PARTS OF BENCH I OF SIDE EXCAVATION SEQUENCES

After completing the pressure chemical injections from the base gallery, it was possible to continue excavating the remaining parts of the station. Next, it was necessary to excavate the side sections, see Fig. 5. This excavation was carried out from the ZS PAD4 construction site via a shaft with a maximum diameter of 7 m. For this reason, it was again not possible to use standard-sized excavation machines for the excavation. Once again, a WIMMER Blue Badger or VOLVO ECR235 tunnel excavator was used, an EPIROC S2 drilling rig, and MEYCO POCA for shotcrete. Excavation began in May 2023 from the already excavated transfer tunnel. Due to limited capacity underground and in the shaft, the top heading of the right-hand section was excavated first, followed by the top heading of the left-hand section, and then parts of the first bench. Standard shotcrete was used for the lining, two layers of KARI mesh 8/150x150 mm, additional bar reinforcement of 12, 16, 20, or 25 mm profiles, lattice girders, and IBO self-drilling steel bolts with a diameter of 32 mm and 51 mm as rod supporting elements. The face was divided into the top heading and the invert of the top heading, bench I and the invert of bench I, with a maximum distance of 6 m for the top heading and 8 m for bench I. The thickness of the primary lining of the top heading or bench I was 550 mm and the invert of the top heading or the invert of bench I was 450 mm. The length of an advance of the top heading was 1 m, the invert of the top heading along with bench I 2 m, and the invert of bench I 4 m.



Fig. 5: Excavation of side profiles

3.4 EXCAVATION OF THE REMAINING PARTS OF THE PANKRÁC D STATION

After finishing the excavation of the first bench, and from the opposite side the turnaround tunnel, a connection was made with the ZS PAD1b construction site facility, where a shaft with a diameter of approximately 20 m is located. The remaining station profiles could be excavated using standard-sized excavators, i.e., the VOLVO ECR355 or LIEBHERR 950 tunnel excavators, while the EPIROC E2C drilling rig and MEYCO POTENZA shotcrete machine were used. At the same time, it was possible to excavate the remaining parts of the side excavations in parallel. In this way, the remaining parts of the top headings and benches I were gradually excavated, see Fig. 6, and the entire length of the benches II and the inverts of the side excavations, see Fig. 7.



Fig. 6: Bench I excavation

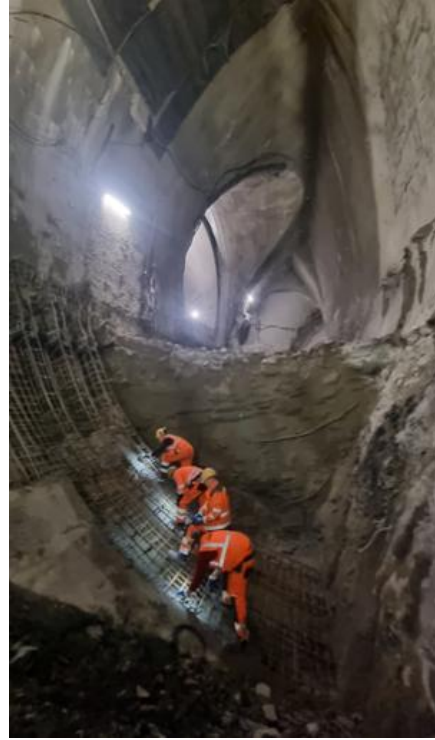


Fig. 7: Bench II and invert excavation

At the point where the excavation of the top heading was finished, a section of the transfer tunnel from the engineering-geological survey was excavated, and this space had to be filled with infill concrete. TERRAFLOW 5 infill concrete was used, with a guaranteed strength of at least 5 MPa. The filling was confined by temporary reinforced concrete walls made of shotcrete and KARI mesh with studs drilled from 32 mm diameter steel IBO rods. The filling was carried out in layers approximately 1.5 m thick, see Fig. 8. A total of ca. 1000 m³ of infill concrete was used.



Fig. 8: Filling the transfer section with TERRAFLOW infill concrete

After excavating the first bench, a cross passage was excavated between the two side excavations at the level of this profile in order to maintain access between them. The profiles of bench II and the invert were finally excavated together with an advance of 2 to 3 m. This connected the side excavations from the lining of the base gallery at the bottom of the station. Subsequently, work could begin on excavating the top heading of the middle excavation. An important part of the excavation was to preserve a certain amount of muck in the station so that excavation could be carried out at different height levels, i.e., after the excavation of the second bench and the invert, it was necessary to leave part of the muck in the station for the subsequent excavation of the middle excavation top heading, which was at a level of approximately 12 m from the bottom of the station. The excavation of the middle excavation top heading began with gradual breaking from the lining of the left partial excavation towards the right. This breaking took place over a length of approx. 7 m, when the entire station profile was connected, and excavation proceeded according to the standard procedure, see Fig. 9. The distance between the excavation of the middle excavation top heading and the possibility of starting the demolition of the temporary internal walls of the side excavations was at least 6 m. According to the project, it was possible to demolish the temporary walls behind the top heading face at a length of 2 m and a maximum of 4 m per day. Further demolition was only possible after a pause of at least 24 hours from the end of the last spraying to secure the station vault after this demolition. After breaking out another approx. 20 m of the central excavation top heading, it was possible to retroactively finish this breakout and connect the remaining part of the central excavation top heading. The breakout was located in the part of the station with the best geology and as far as possible from surface structures, especially the operating metro C line and the GEMINI building. At the time of writing this article, approximately 50 m of the central excavation top heading remains to be completed, as well as the majority of the core excavation of the central sub-excavation and the demolition of the internal temporary structures. Finally, a 12 m long section of the station will be excavated downward across the entire width of the invert for cable crossings and space for a pumping sump.



Fig. 9: Middle profile top heading excavation

3.5 THICKENED PRIMARY LINING OF THE PANKRÁC D STATION

At the intersection of the station and the future transfer tunnel, directly beneath the operational Metro C line, the mining engineer designed thicker primary lining for structural reasons. The thickened lining was constructed over a length of approximately 20 m. For this reason, the excavation in these areas was raised by 550 mm. Three layers of KARI mesh 8/150x150 mm, shotcrete, additional bar reinforcement with a diameter of 16 mm, and coupling studs made of self-drilling IBO steel rods with a diameter of 32 mm and a length of 1.5 m were used to reinforce the lining, see Fig. 10.



Fig. 10: Thickened station lining

4. CONCLUSION

The excavation of the single-vault Pankrác D station with a cross-section of approximately 400 m² in complex geotechnical conditions in close proximity to the operational metro C line at the station of the same name and in the vicinity of other above-ground (e.g., the GEMINI building) and underground structures (e.g., the PRE utility tunnel) required very close cooperation between all parties involved in the construction, from the designer, through monitoring, investor supervision, and the investor, to the contractor. At the same time, the relevant mining authority and experts in project documentation were an integral part of the control process. In the early stages of construction, this task seemed difficult to accomplish. It was only the results of the engineering-geological survey and the subsequent technical solution, primarily in the use of chemical pressure grouting but also chemical mixtures as fillers for all support elements, that provided reassurance, but those involved in tunnel excavation know that this reassurance only comes after the excavation is complete. The excavation of the Pankrác D station required great care, precision, and experience on the part of the excavation crews, with strict adherence to technological discipline. On the other hand, due to the large thickness of the primary lining (550 mm), cavities formed at the interface with the excavation at the constructed lattice girder, and in order to minimise them, it was necessary to spray these cavities after excavating the next advance and before constructing the next lattice girder.

References

- PRAVDA, V. *Generální projekt trhacích prací METRO D, Úsek stanice Pankrác a související objekty*. Praha, 2021, 20 s.
- URBÁNEK, T. *Dokumentace pro provedení stavby: Výstavba trasy I.D metra v Praze – úsek ID1a, Stanice Pankrác D, Ražba a primární ostění, Patní štola ražená z VO-OL*. Praha: METROPROJEKT Praha a.s., 2022.
- URBÁNEK, T. *Dokumentace pro provedení stavby: Výstavba trasy I.D metra v Praze – úsek ID1a, Stanice Pankrác D, Zlepšení horninového masivu, Injektáže z VO-OL*. Praha: METROPROJEKT Praha a.s., 2023.
- URBÁNEK, T. *Dokumentace pro provedení stavby: Výstavba trasy I.D metra v Praze – úsek ID1a, Stanice Pankrác D, Ražba a primární ostění, Pravý dílčí výrub*. Praha: METROPROJEKT Praha a.s., 2023.
- URBÁNEK, T. *Dokumentace pro provedení stavby: Výstavba trasy I.D metra v Praze – úsek ID1a, Stanice Pankrác D, Ražba a primární ostění, Levý dílčí výrub*. Praha: METROPROJEKT Praha a.s., 2023.
- URBÁNEK, T. *Dokumentace pro provedení stavby: Výstavba trasy I.D metra v Praze – úsek ID1a, Stanice Pankrác D, Ražba a primární ostění, Střední dílčí výrub*. Praha: METROPROJEKT Praha a.s., 2025.

Title, first name, last name of author: Václav Anděl

Workplace: Subterra a.s.

Email address: vandel@subterra.cz

Title, first name, last name of author: Ing. Štefan Ivor

Workplace: Subterra a.s.

Email address: sivor@subterra.cz