CABLE DUCT EXCAVATION USING A MECHANISED SHIELD AT KOLÍN RAILWAY STATION – AUTONOMOUS GEOTECHNICAL MONITORING OF THE TRACK SYSTEM

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The project "Ensuring barrier-free access to the platform at Kolín railway station" aimed to rebuild the existing underpass beneath the platform in Kolín and to transfer the utility networks to a newly constructed cable duct in the immediate vicinity of the railway station. The 88-metre-long cable duct was constructed at the end of 2024 using a HERRENKNECHT mechanised bentonite shield with a diameter of 3 meters. The cable duct runs perpendicular to 16 transport tracks in a geological environment of fluvial sediments of the Elbe River. The fillings and weathered orthogneiss have a cover thickness of approximately 5 meters and the entire length of the excavation is below the groundwater level. The excavation was carried out during full operation, which is why the proposed geotechnical monitoring activities were particularly important for ensuring the safe progress of construction and monitoring the impact on its immediate surroundings. Construction monitoring was carried out using automatic IOTIN tilt sensors from INSET s.r.o. and levelling measurements of the transport tracks. Throughout this period, the excavations encountered several issues related to the loose, sandy subsoil. Levelling measurements and sensors in automatic mode with online display made it possible to record adverse track deformations. Thanks to this, the contractor was able to respond to the situation with the appropriate technical measures.

1. INTRODUCTION

As part of the construction of barrier-free access to the platform at Kolín railway station, a new cable duct was excavated, which was designed as a combined structure. The total length of the cable duct was 401.0 m. Of this, 87.0 m was constructed using mechanized excavation. During the excavation, a bentonite "hydro" shield with a diameter of 3.0 m (Figs. 1, 2) was used, which was guided perpendicularly under the tracks with an overburden thickness of approximately 5.0 m. The lining of the cable duct was made of a prefabricated reinforced concrete structure – a total of 29 segments with an inner diameter of 2.5 m and a length of 3.0 m per segment. The northern launch shaft for mechanized excavation using a bentonite shield was located on Starokolínská Street, and excavation then continued towards the southern target shaft located on platform 1 (Fig. 3).

Figure 1: View of the cutting head of the bentonite shield.

Figure 2: Preparation of the tunneling machine in the shaft.

2. ENGINEERING GEOLOGICAL AND HYDROGEOLOGICAL CONDITIONS

The uppermost surface of the terrain at the site of interest was modelled by recent anthropogenic sediments, i.e., fill (geotype AN), railroad ties, and diverse, but predominantly rocky-sandy fill. The total thickness of the AN horizon was generally 1.0 to 2.0 meters. The subsoil of the fill consists of Quaternary fluvial sediments of the Elbe River, which are mainly composed of weakly cohesive, sandy to gravelly-sandy soils (geotype FL1), but often also include layers of fine-grained loamy and clayey-sandy soils, in places possibly with a muddy admixture (geotype FL2). The thickness of the fluvial sediments is mainly 3 to 6 meters, and their base is located at a depth of approximately 4.5 to 7.0 meters below ground level (i.e., at an elevation of approximately 194.5 to 192.0 meters above sea level) (Síla and Březina 2019).

At this approximate level, there is also the surface of the bedrock, formed by two-mica orthogneisses (or even migmatites), which are characteristic rocks of the bedrock in the locality and its wider surroundings (Kutná Hora crystalline complex, Paleozoic; geotype KK), gradually transitioning in depth from completely weathered W5 (eluvium) through strongly and moderately weathered W4 and W3 to solid weathered and sound rock W2 and W1 (Síla and Březina 2019).

Under prevailing atmospheric conditions, groundwater occurs at a depth of 3 to 5 m below ground level, i.e., at an elevation of ~196.3 to 194.7 m above sea level, in the FL1/FL2 fluvial sediment horizon. At the location of the cable duct launch shaft, the groundwater level was approximately 4.7 m below the ground surface, i.e., above the tunnel canopy, and rose slightly towards the target shaft (Síla and Březina 2019).

Excavation in the launch shaft began in soil, and approximately halfway through the route, it entered the excavated profile of the gneiss base, which gradually formed an increasingly larger proportion of the excavation area. The final part of the excavation took place entirely in the rock mass, where strength tests verified the strength of the rock to be up to 180 MPa in simple compression (Venclová et al. 2025).

3. GEOTECHNICAL MONITORING

Geotechnical monitoring was an integral part of the construction of the new underground structure. Kolín railway station has a total of 16 tracks, 14 of which were located in the affected zone. The railway station is part of an important railway corridor, so it was necessary to ensure that mechanized excavation did not restrict traffic on the line in any way.

The scope and method of monitoring (Fig. 3) were developed in accordance with the principles of mechanized excavation, as well as with the principles of the observation method, the principle of which is to set limit values for individual measurement methods, which also become warning values. Similarly, in the case of monitoring this construction, all measurements were recorded, processed, and immediately forwarded to all participants in the construction.

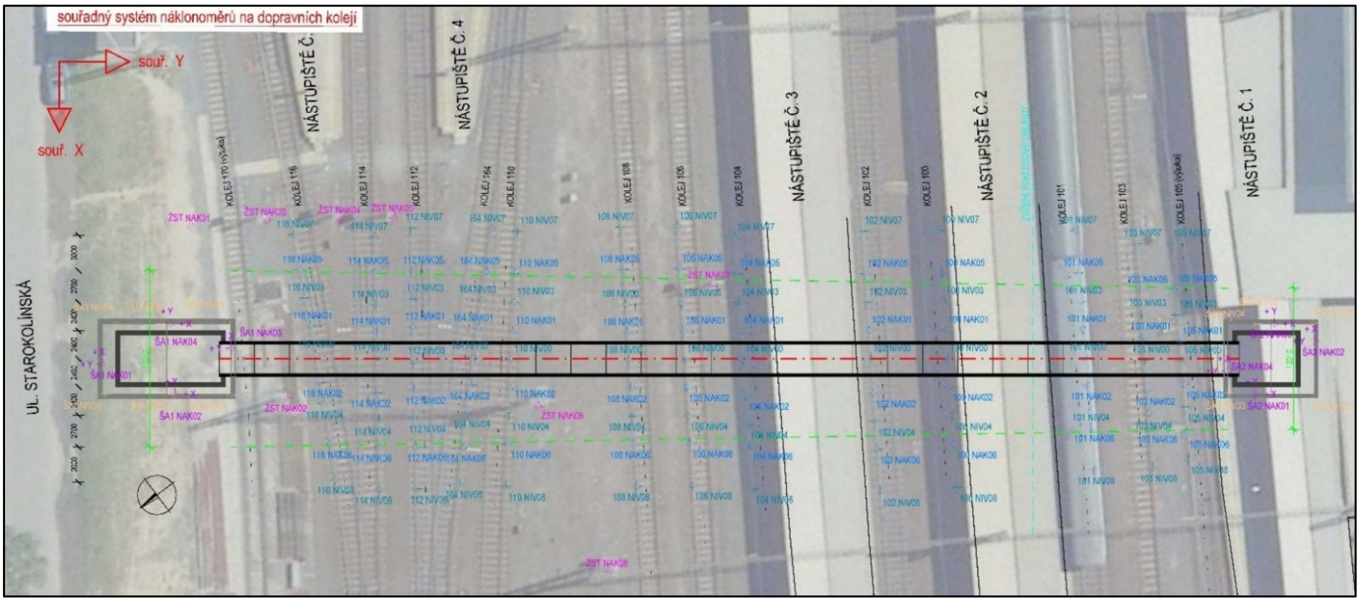


Figure 3: Location of autonomous monitoring points on the track.

During excavation, the results were transmitted to construction participants in the form of "live" data via the MINER web application from INSET s.r.o. Given the need for immediate information about what is happening on the construction site (current measurement data) and the amount of this data, digital display (including graphical and tabular outputs), enabling interactive display of values, descriptions, etc., is practically the only option for meaningful and clear online display of geotechnical monitoring results.

4. RANGE OF MEASURED POINTS AND WARNING STATES

Before the start of construction work, a total of 13 measuring profiles consisting of 9 levelling points were set up to monitor the zone of influence (a total of 117 points, see Fig. 3). The main measuring point was set in the axis of the excavated structure and the remaining points were set mirror-like in two rows on concrete sleepers approximately 2.4, 4.8, 7.8, and 10.8 m away from the excavation axis to cover the zone of influence.

Furthermore, associated elements of the station, i.e., concrete bases of masts, traction line masts, and signals, were surveyed. A total of 8 levelling points were installed to measure height changes.

In the case of both shafts, 6 levelling points were installed at the starting shaft and 5 levelling points at the target shaft.

INSET s.r.o.'s IOTIN tilt sensors with a measurement accuracy of 0.01 mm/m and a specific measurement range of -30° to +30° were used to monitor the tilt of the transport tracks and the associated part of the station. The measurements themselves were performed in automatic mode with a reading frequency of 1 to 5 minutes. Sensors located at stations 0.0 to 40.0 m from the starting shaft sent the measured values once per minute. Such a short interval was chosen due to the unfavourable geological conditions encountered (fluvial sediments of the Elbe River). From station 40.0 m, the measurement frequency was set to 5 minutes.

Limit values for declines were proposed for measuring inclinations on the transport track and concrete sleepers. These limit values were set by the designer in accordance with the ČSN 73 6360-2 standard. They were based on operational deviations and the AL (Alert Limit) monitoring limit, which was set as a level 3 warning. The warning states for tilt sensors and levelling measurements are listed in the following tables (Tables 1 and 2).

Table 1: Overview of warning states for tilt sensors.

WARNING STATUS	**transport tracks in the longitudinal direction in the X direction** (transverse to the axis of the excavation)	**traffic lanes in the transverse direction in the Y direction** (longitudinal to the excavation axis)	**selected elements of Kolín railway station, in particular traction line poles** (TV)
I. estimated value, no action required	**8 mm/m**	**2 mm/m**	**5 mm/m**
II. higher value, still within expectations, it is necessary to increase the frequency of measurements and pay closer attention to monitoring other measured values – measures will be agreed upon within the monitoring council	**12 mm/m**	**3 mm/m**	**10 mm/m**
III. values exceeding the monitoring limit, measures must be taken to prevent further decline – measures will be agreed upon within the monitoring council	**16 mm/m**	**4 mm/m**	**15 mm/m**

Table 2: Overview of warning conditions for levelling point drops.

WARNING STATUS	**leveling measurement of transport tracks**	**selected elements of Kolín railway station, in particular traction line poles** (TV)	
I. estimated value, no action required	**8 mm**	**5 mm**	
II. higher value, still within expectations, it is necessary to increase the frequency of measurements and pay closer attention to monitoring other measured values – measures will be agreed upon within the monitoring council	**12 mm**	**10 mm**	
III. values exceeding the monitoring limit, measures must be taken to prevent further decline – measures will be agreed upon within the monitoring council	**16 mm**	**15 mm**	

5. EXCEPTIONAL EVENTS

Before the actual excavation, two interesting events occurred in connection with the application of jet grouting in the vicinity of the launch shaft. The design of the construction pits was based on the latest information obtained during the engineering-geological survey in 2019 (Síla and Březina 2019) and the supplementary geophysical survey in 2023 (Minář, 2023). The design of the construction shafts was based on these surveys. The launch shaft was designed in the classic way using sheet piling, with a length of 16.5 m and bracing at three levels of 2.1 m, 4.3 m, and 9.1 m (working level 199.7 m above sea level). From the outset, the project also included measures to protect the entire launch shaft in the form of jet grouting columns around the perimeter of the shaft, under the bottom of the shaft and behind the shaft, into the overburden of the future cable duct. The jet grouting columns were designed with a diameter of 1,200 mm, with their bases ending 2.00 m below the bottom of the launch shaft excavation. The length of the jet grouting columns forming the encircling screen of the shaft was 8.0 m (Ježek and Pikhartová 2024).

Even before the actual excavation with a mechanized shield, the first round of grouting on October 17, 2024, caused deformation of the overburden due to jet grouting in the vicinity of the launch shaft. The first warning level was exceeded on the adjacent mast marked 268A and the signal marked Lc116c, which was well documented in relation to the zero measurement, as can be seen in the graph in Figure 4. The leveling measurement even showed a rise of +27.42 mm (3rd warning level = ± 15.00 mm).

Figure 4: Graphical output from measurements taken by the tilt sensor on mast 268A.

During the excavation of the launch shaft itself, despite all the special foundation work, on November 25, 2025 (depth of the clean excavation of the shaft approx. 9.2 m below ground level), large volumes of fine-grained material (fluvial sandy sediments and clayey soils) washed through the shoring and bottom of the construction shaft. This occurred to such an extent that the surface outside the retaining wall collapsed (Fig. 5). It was then necessary to flood the construction shaft to approximately two-thirds of its depth (Fig. 6) to prevent its bottom from breaking through. This was followed by a second round of jet grouting, which successfully sealed the sources of the leaks. As these were locations outside the operational track, it was not necessary to take any measures related to train operations.

Figure 5: Surface subsidence at the launch shaft.

Figure 6: Flooding the shaft to prevent bottom break through.

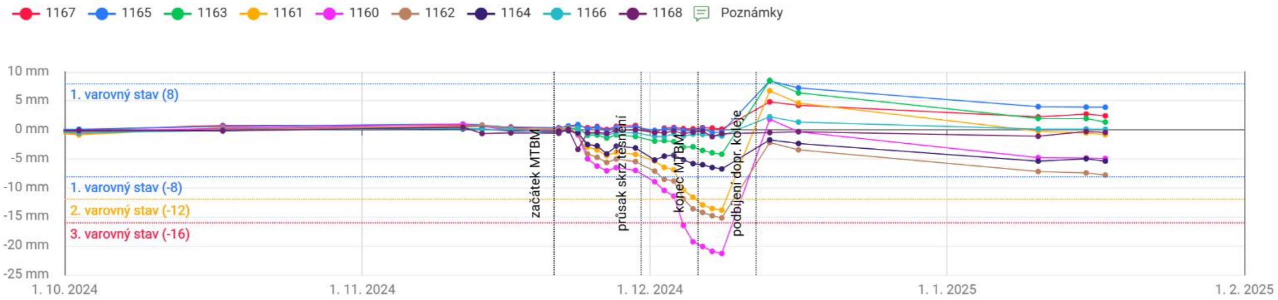
6. MONITORING RESULTS

All measurements described above were performed between September 24, 2024, and January 17, 2025. Before the start of mechanized excavation, measurements were taken to document the "resting" state of the rock environment and to record the effects of surrounding conditions (the impact of climatic conditions on monitoring). The resting state was measured until November 21, 2024, when mechanized excavation began, which lasted a total of 16 days. Subsequently, the remaining segments were pushed through the rock environment. From December 12, 2024, remediation work was carried out in areas of greater settlement, followed by measurements of the resting state to document the stability of the rock environment. Subsequent levelling measurements verified the stability of the rock environment, specifically by achieving measured values in three measurement stages with a maximum measurement error difference (0.2 to 0.5 mm).

At the location of the transport tracks, tilt sensors measured the inclination in two directions, namely in the X direction (transverse to the excavation axis) and in the Y direction (longitudinal to the excavation axis), in order to record any elevation or collapse of the track. The measurement was supplemented by levelling measurements.

In the first 40 meters from the starting shaft, the mechanized excavation itself did not have a significant impact on the subsidence of the transport tracks. One of the largest subsidence events in this section was recorded on track No. 116 at a stationing of 8.1 m from the starting shaft in connection with massive groundwater seepage through the seal between a pair of segments. The seepage was probably caused by poor contact between the concrete section and the seal. The total change in the measured tilt values in the X direction was ±4.80 mm/m (1st var. state = ±8.00 mm/m), while the tilt measurements in the Y direction reached maximum values of ±1.80 mm/m (1st var. state = ±2.00 mm/m) (shown in Fig. 6).

As part of the levelling measurement, the leakage between the two segments manifested itself in a drop in the measured track, when on December 1, 2024, the first warning level (= -8.00 mm) was exceeded with a measured value of -8.95 mm in the excavation axis. Three days later, the third warning level (= -16.00 mm) was exceeded with a measured value of -16.47 mm. The overall drop was also influenced by the subsequent pushing through of the remaining segments, with a value of -21.31 mm measured on December 8, 2024 (Fig. 6). Subsequently, the transport track was underpinned and its safety assessed in terms of GPK (geometric position of the track). The measured values in the excavation axis gradually stabilized at around -5.00 mm.



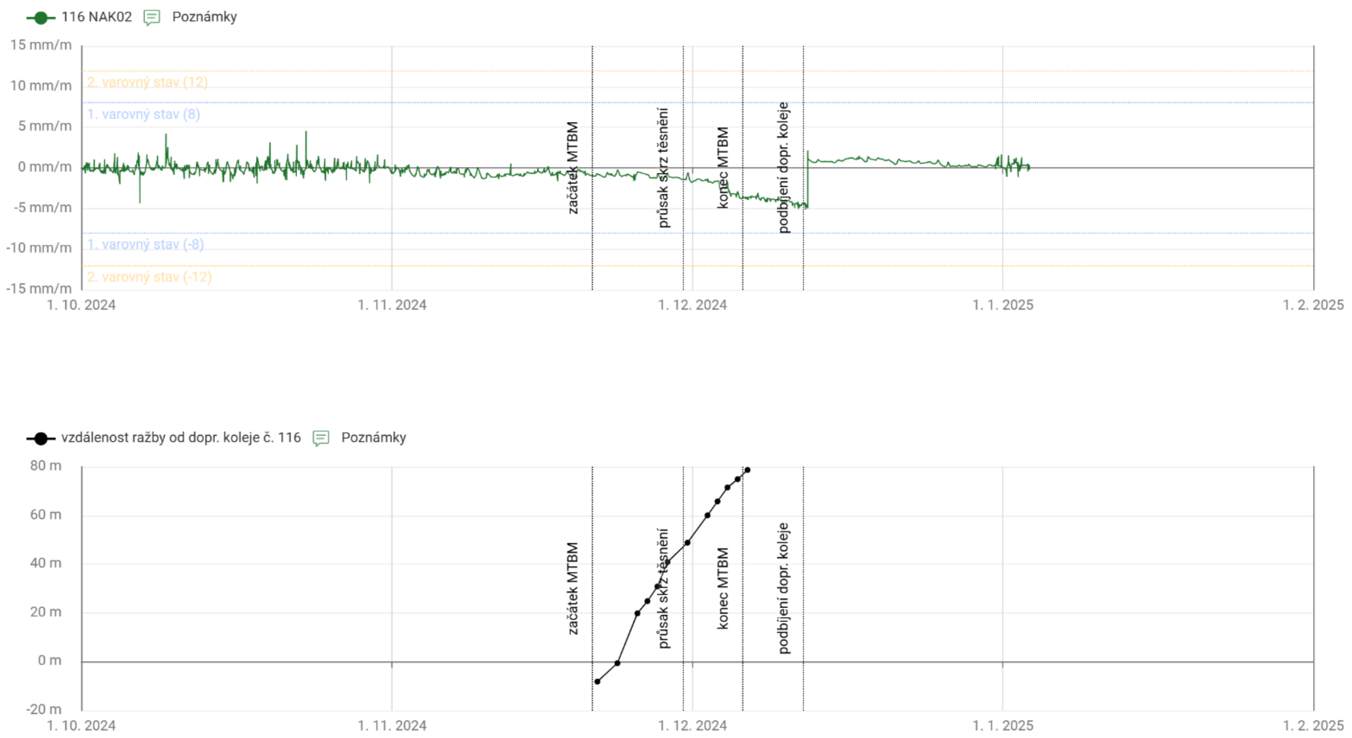


Figure 6: Graphical output of the levelling measurement of track No. 116 and measured values on the 116 NAK02 tilt sensor in the X direction.

In the subsequent section of the excavation from 40.0 m to 82.0 m, at the time of intersection with mechanized excavation, a gradual change in both directions was observed on the tilt sensors in the characteristic V-shaped decline (i.e., the greatest decline directly above the excavation axis). Slight declines were also evident in the levelling measurements, where the declines specified in the project occurred during the mechanized excavation (no warning condition was exceeded). However, significant declines subsequently occurred during the pushing of individual segments. The tilt sensors recorded a first warning condition (1st warning condition = ±8.00 mm/m) on track no. 101 (= ±9.00 mm/m) and a second warning condition (= ±12.00 mm/m) on track no. 103 (= ±13.00 mm/m). In the Y direction, the first warning condition (= ±2.00 mm/m) was recorded on track no. 103 (±2.50 mm/m) and on track no. 105 (±2.90 mm/m). A change in the rock environment (subsidence) was also recorded during the levelling measurement. There was an overall settlement of the track to values with a maximum of around -35 mm (exceeding the 3rd warning level = -16.00 mm). Following the measured deformations and exceeding of warning levels, some tracks were tamped and subsequently assessed in terms of safety according to the geometric position of the track, which always had to comply.

In general, the measured data show that, in the case of inclination measurements, the third warning level was not exceeded during construction and the first or second warning levels were rarely exceeded, whereas in the case of levelling measurements, the third warning level was exceeded repeatedly. For future tasks of a similar type, these findings could be used to determine warning levels. Specifically, in geodesy, it was verified that the limits were set too strictly (of course, everything is fundamentally related to local geology).

7. CONCLUSION

The construction of a cable duct under the operational track using microtunnelling has proven to be a suitable method for combining and transferring cabling under the railway track without the need for closures and significant traffic restrictions. Consistent monitoring of the operating parameters on the cutting head of the AVN2000AH Herrenknecht tunnelling machine, supplemented by geotechnical monitoring of the tracks and surrounding structures, was an integral part of the basic requirement for the safe execution of the new underground work. Precise monitoring of height changes by levelling measurements was supplemented by automatic rail inclination measurements using sensors, without restricting mechanised tunnelling and rail transport. The rapid display of data in the MINER online application with timely evaluation of the measured data in relation to warning conditions was also crucial.

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