RESULTS OF GEOTECHNICAL MONITORING OF THE HOMOLE TUNNEL PROVIDED BY THE CONTRACTOR

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ABSTRACT: The construction of the D35 motorway section Ostrov–Vysoké Mýto is a key component of the road infrastructure in the Pardubice Region, with its most significant structural element being the Homole Tunnel. The tunnel passes beneath Homole Hill, and its construction faces several geotechnical challenges that significantly affect both the construction process and subsequent operation. An integral part of the construction is geotechnical monitoring (GTM), which is a crucial process ensuring the safety and stability of tunnel structures. The monitoring includes various techniques and methods used to observe geotechnical conditions and material behavior before construction, during construction, and after completion of the works. Geotechnical monitoring at the Homole Tunnel construction site is divided into two parts. The first consists of monitoring carried out by the client's representative, which includes geological observation of tunnel faces and excavation pits, measurement of deformations of the primary and secondary linings, measurement of stresses in the final lining, and monitoring of hydrogeological conditions. The second part consists of geotechnical monitoring carried out by the contractor. This group includes condition surveys of structures within the zone of influence, measurements of trigonometric control points on the terrain, monitoring of above-ground structures and utilities, measurements of dynamic and acoustic effects, monitoring of stresses in the primary lining, inclinometer measurements, extensometer measurements, and measurements at tunnel portals and excavation pits.

1. INTRODUCTION

The construction of the D35 motorway section along the Ostrov–Vysoké Mýto route represents one of the key investments in the development of road infrastructure in the Pardubice Region. The most significant structure of this section is the Homole Tunnel, which runs beneath the hill of the same name. Its design and construction have been accompanied by a number of geotechnical challenges that have a major impact on both the construction process and the subsequent operation of the tunnel. An integral part of the project is therefore geotechnical monitoring (GTM), which represents an essential tool for ensuring the safety and long-term stability of tunnel structures. The monitoring comprises a set of methods and measurement techniques focused on observing geotechnical conditions and the behaviour of the rock mass and structural elements before the start of construction, during construction, and after completion of the works.

The tunnel is located northeast of the village of Vraclav, where the D35 motorway passes beneath a ridge with Homole Hill. The motorway is designed in category R 25.5/120, with the width of the central median increased from 3.0 m to 3.5 m. The tunnel consists of two unidirectional tunnel tubes, with the left tube having a length of 525 m (of which 180 m is cut-and-cover and 345 m is mined) and the right tube having a length of 569 m (of which 120 m is cut-and-cover and 449 m is mined) (Fig. 1). Including the tunnel sections, the total length of the structure is 795 m. The two tunnels are connected by one cross passage with a length of 17.5 m. The overburden thickness in the mined section of the tunnel ranges from 8.5 to 24 m above the left tunnel and from 7 to 19 m above the right tunnel. Both tunnel tubes pass beneath the heavily trafficked Road I/17. The crossing angle between the tunnel tubes and the road is approximately

30°. The overburden thickness at the undercrossing of Road I/17 is approximately 13.5 m. The design of the mined section of the tunnel is implemented under contractual conditions based on the FIDIC Yellow Book, with selected elements of the Emerald Book. The contracting authority is the Road and Motorway Directorate of the Czech Republic (ŘSD), while the contractor is the consortium "Company for the Construction of D35 Ostrov–Vysoké Mýto, Homole Tunnel" consisting of EUROVIA CZ a.s., MARTI a.s., and EUROVIA SK, a.s. The tunnel designer is Amberg Engineering Slovakia, s.r.o., and the designer of the mined section is AMBERG Engineering Brno, a.s. Tunnel excavation was carried out by MARTI a.s. The contractor for the client's geotechnical monitoring works is INSET s.r.o., while geotechnical monitoring works for the contractor are provided by GeoTec-GS, a.s.

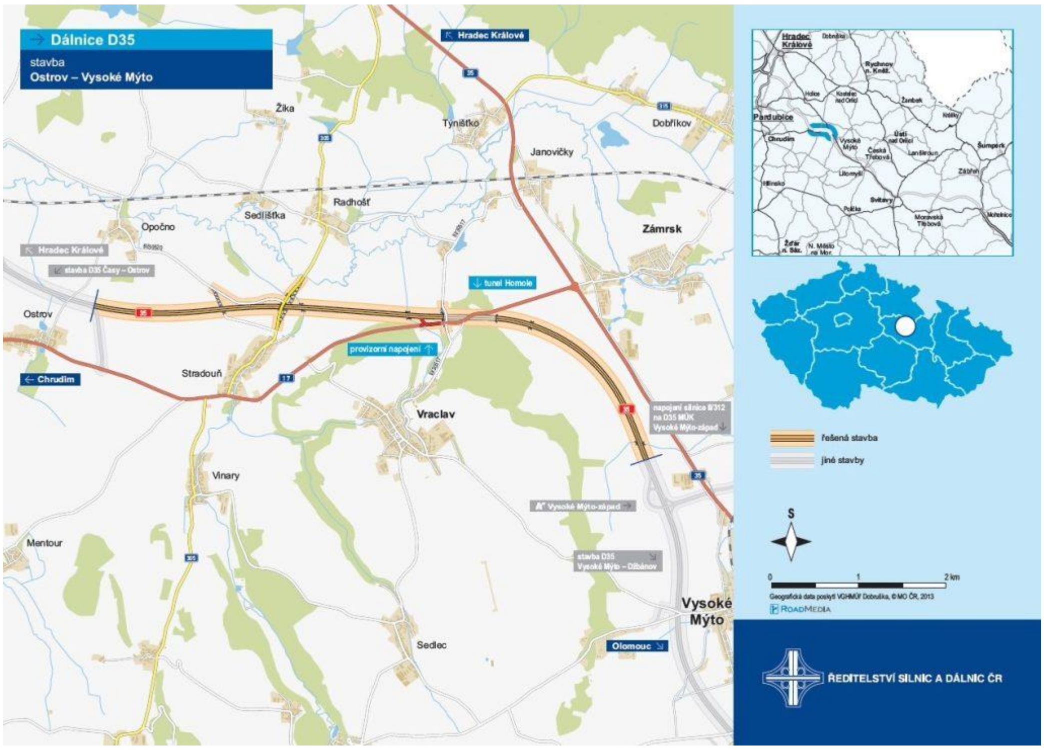

Figure 1: Overview of the construction of the D35 motorway Ostrov - Vysoké Mýto.

2. GEOLOGICAL CONDITIONS

The area of interest is located on the eastern margin of the Bohemian Cretaceous Basin. From a lithological point of view, the encountered fine-grained Upper Cretaceous sedimentary rocks can be classified as a transitional phase between the Orlice–Žďár and Elbe lithofacial developments. The Homole Tunnel passes through the Vraclav Ridge massif. During tunnelling, layers of genetically diverse Quaternary soils were encountered, as well as bedrock formations represented in the area by Cretaceous sandy marlstones and siltstones with local transitions to limestones. The structural arrangement of individual bedrock layers is significantly influenced by the complex geological evolution of the area. In the area of the western tunnel portal, the bedding of the Cretaceous rocks shows a very gentle dip of approximately 5° toward the east-southeast (ESE). Approximately 100 m east of the eastern portal, the Vraclav anticline is markedly tectonically bounded by a fault along which a relative downthrow of the eastern limb of up to 200 m has been documented. In the section approximately between chainages km 35.800–36.000, boreholes reveal a pronounced increase in bedding dip toward the ESE, reaching values exceeding 35°, accompanied by bending of the strata. This tectonically induced fold has been described in the past as the so-called Malejov flexure. The marlstones and siltstones encountered in the Vraclav Ridge area represent marine sediments of the Jizera Formation of Middle to Upper Turonian age. Based on the results of a detailed geotechnical investigation for the D35 Ostrov–Vysoké Mýto project, the following geotypes were defined for the Homole Tunnel. Geotypes K1a and K1b represent eluvial, completely weathered sandy claystones and siltstones of soil-like character. Geotype K2 consists of highly weathered sandy marlstones and siltstones of strength class R5. Moderately weathered sandy marlstones and siltstones form geotype K3. The highest quality rock mass is represented by fresh to slightly weathered marlstones and siltstones (geotypes K4 and K5) with strength classes R3–R2. The Quaternary cover deposits along the Homole Tunnel alignment can be divided, in terms of genesis, into anthropogenic sediments (fills), aeolian to aeolian–deluvial sediments (loess and loess-like soils), fluvial sediments (relicts of the alluvium of the Loučná River), and deluvial, i.e. slope deposits. In particular at the base of the Quaternary cover, several-metre-thick layers of slightly gravelly grey-brown clays with a muddy odour and variable consistency, ranging from stiff to soft, were relatively frequently recorded. These soils are most likely largely composed of infill of a former river channel mentioned above.

The hydrogeological conditions of the Homole Tunnel area are controlled by climatic conditions together with geomorphological and drainage characteristics, geological-tectonic structure, and other factors. These factors influence the proportion of infiltrated precipitation contributing to the recharge of groundwater resources within geological structures and to the formation of their physico-chemical properties. Groundwater inflows identified during tunnelling were exclusively associated with fault zones, open systems of persistent discontinuities, and fractures. The inflows mainly occurred as dripping water; to a lesser extent, measurable inflows in the range of 0.05–0.2 l/s were also observed. The total groundwater discharge from the tunnel tubes during excavation ranged between 2 and 4 l/s (Korba and Čillik 2025).

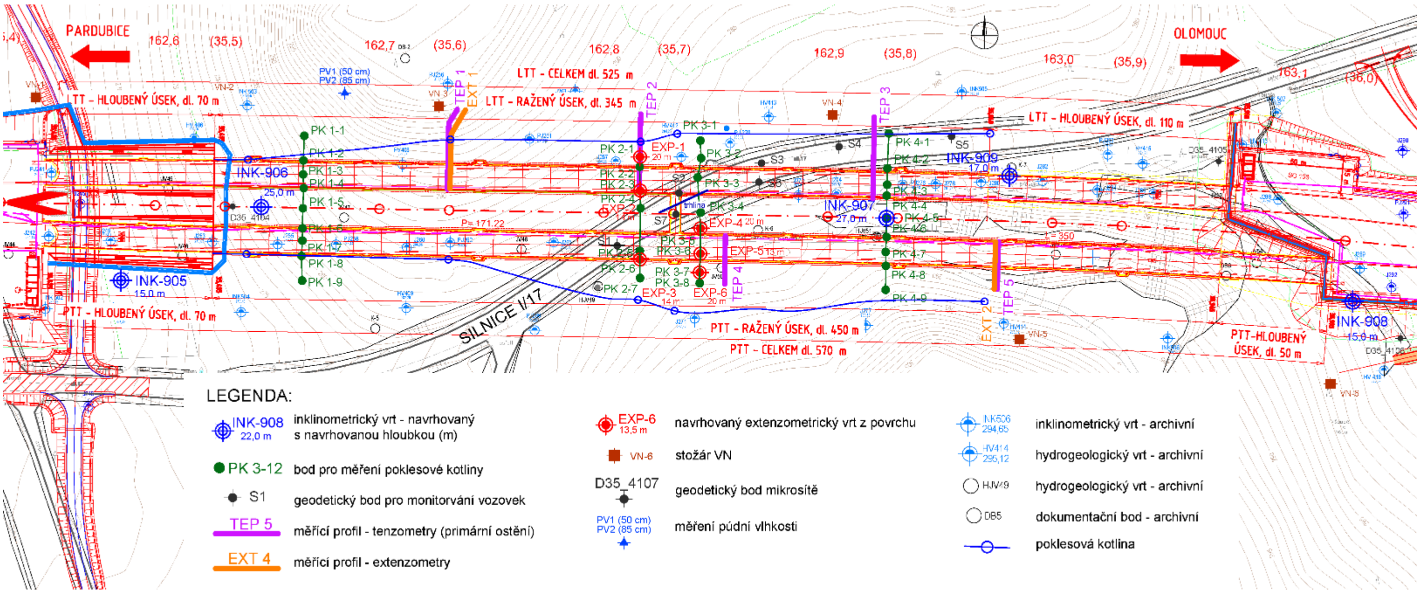

Figure 2: Location of monitoring objects in the Homole tunnel.

3. GEOTECHNICAL MONITORING OF THE HOMOLE TUNNEL

The phases of geotechnical monitoring of structures (GTM) are usually divided into a preliminary stage prior to the commencement of construction works, which includes preparatory activities and investigations; a construction stage, during which safety, operational, and periodic measurements are carried out to monitor the progress of construction and verify stability; and a post-construction stage focused on long-term monitoring. These stages enable systematic observation of deformations, assessment of structural stability and its impact on the surrounding environment, and serve to ensure safety, optimize construction methods, and verify the validity of design models. Geotechnical monitoring of the Homole Tunnel, including the implementation design, was provided by the Contractor, with the exception of geological observation of tunnel faces and excavation pits, measurement of deformations of the primary and final linings, measurement of stresses in the final lining, and monitoring of hydrogeological conditions, which form the fundamental basis for the evaluation of key criteria in accordance with the GBR.

The objective of this paper is to describe and characterize selected geotechnical monitoring methods applied at the Homole Tunnel during the construction phase. The paper also includes an evaluation of the results of hydrogeological monitoring along the D35 Ostrov–Vysoké Mýto motorway, including the Homole Tunnel.

3.1 MEASUREMENT OF THE SETTLEMENT TROUGH AND SETTLEMENT OF ROAD I/17 SURFACE

Measurement of ground surface settlement above the tunnel tubes was carried out using geodetic trigonometric methods. The output of the measurements was the elevation of each point determined trigonometrically. Prior to the commencement of construction works, geodetic points were stabilized on the ground surface and arranged in transverse profiles so as to cover the full width of the settlement zone assumed in the design. The first monitoring profile, PK1, was installed above the western portal at chainage 39.8 tm. Two profiles, PK2 (190.0 tm) and PK3 (217.0 tm), are located approximately in the central section, at the locations where the tunnel tubes pass beneath road I/17. Another profile, PK4 (300.0 tm), is situated near the eastern portal (Fig. 2). From the perspective of ground surface deformation development, the most informative results were obtained from profiles PK2, PK3, and PK4. At profile PK2, the maximum ground surface settlement was recorded at point PK2-5 (−43 mm) above the right tunnel tube (RTT). Higher settlement values were identified at profile PK3, specifically at points PK3-5 (−47 mm) and PK3-6 (−51 mm), again located above the right tunnel tube. The highest settlement values were measured at profile PK4 at points PK4-5 (−51 mm), PK4-4 (−82 mm), and PK4-3 (−94 mm) above the left tunnel tube (LTT) (Fig. 3). Above the RTT, settlement values at profile PK4 reached up to −46 mm (point PK4-6). The designer specified the limiting value of ground surface settlement as A = 40 mm. The first manifestations of ground surface deformation at the monitored profiles began to appear approximately 10 m ahead of the crown position in the respective tunnel tube. The greatest increase in deformation was observed during the passage of the crown and the core beneath the monitoring profile.

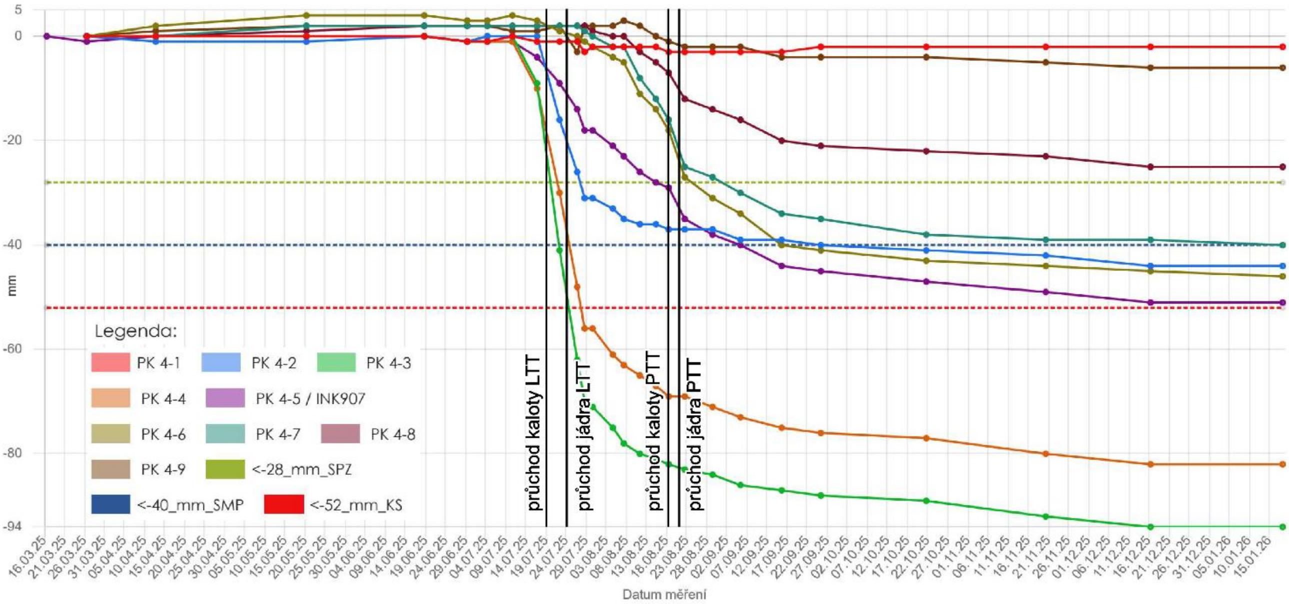

Figure 3: Development of terrain surface settlement on profile PK4.

In parallel with the settlement trough measurements, settlement of the surface of road I/17 was also monitored. The Homole Tunnel passes beneath the heavily trafficked road I/17 at an angle of approximately 30°, with an overburden thickness ranging from about 12.0 to 14.1 m. Settlement of Road I/17 above the tunnel tubes was measured using geodetic trigonometric methods. For safety reasons, geodetic points on the operating roadway were equipped with special prisms designed for pavement monitoring. A total of five special geodetic prisms were proposed in the GTM design. Based on the recommendation of the RAMO board, two additional points (S6 and S7) were added.

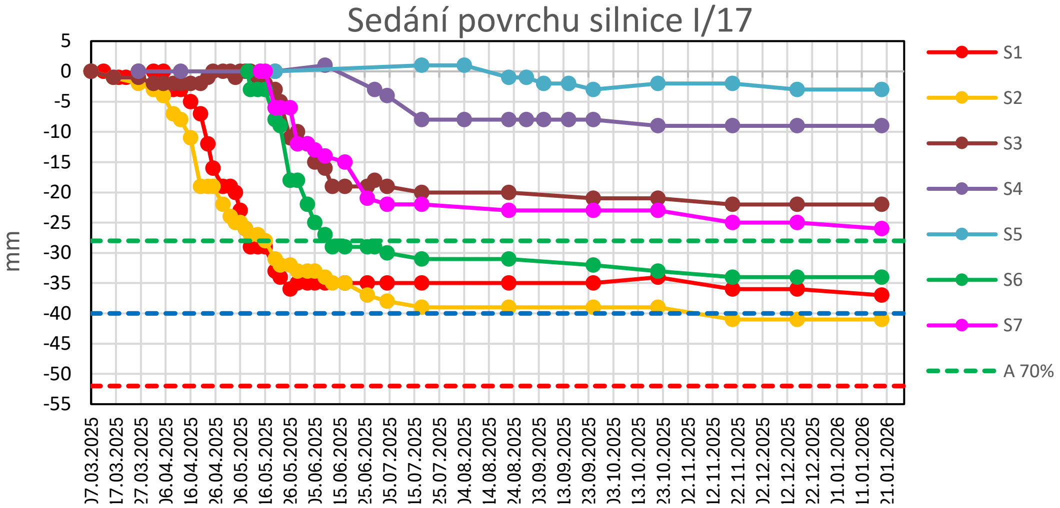

Figure 4: Development of road surface settlement on I/17.

Measured settlement values ranged from −3 to −26 mm. Higher settlement values were recorded at point S6 (−34 mm; A = 85%) above the left tunnel tube and at point S1 (−37 mm; A = 93%) above the right tunnel tube. The highest settlement value was recorded at point S2 (−41 mm; A = 103%), which is located above the left tunnel tube (Fig. 4). The greatest increases in deformation were observed during the passage of the crown and the core beneath the monitoring points. This was followed by a stabilization phase and a subsequent gradual attenuation of deformations.

Figure 5: Location of cracks on the surface of road I/17.

Part of GTM involved monitoring and measuring faults in above-ground structures such as roads and high-voltage pylons. On May 16, 2025, a crack was discovered on the surface of road I/17 during a site inspection (Fig. 5). It was a longitudinal crack in the central dividing strip, directly above junction no. 1. Due to excavation and residual deformation after core removal, the existing crack widened (lengthened). According to the new survey, the observed crack is approximately 23 m long and approximately 2 to 7 mm thick.

3.2 EXTENSOMETER MEASUREMENTS

Comprehensive monitoring of the rock mass response to tunnelling and its interaction with the primary lining was carried out at several main monitoring profiles located in characteristic sections of the excavation, defined by overburden thickness, geotechnical conditions, or excavation geometry. In addition to standard convergence measurements monitoring deformations of the supported excavation perimeter (client's GTM), radial extensometer boreholes were installed at these profiles within the tunnel to assess the extent of the deformation zone around the excavation. Extensometers installed from within the tunnel were placed at two profiles. One profile (EXT1) was located in the left tunnel tube at chainage 98.0 tm. The second profile (EXT2) was installed at chainage 350.0 tm in the right tunnel tube. At each profile, three-point extensometers with lengths of 3, 6, and 9 m were installed. Deformation magnitudes recorded by the tunnel extensometers ranged from −0.2 to −3.9 mm. The most pronounced deformation (−3.2 to −7.4 mm) was caused by the passage of the core beneath profile EXT2.

To monitor vertical deformations of the rock mass above the excavation (and loosening of the rock environment), six surface-installed extensometers (EXP1 to EXP6) were installed as part of the GTM prior to the start of tunnelling. The boreholes were located at sites with expected increased deformations, namely at the crossings of the left and right tunnel tubes with Road I/17. Their locations are shown in Fig. 2. At boreholes EXP2, EXP3, and EXP5, three measurement levels were installed: the shallowest at approximately 4.5–5.0 m, the intermediate at approximately 9.0–9.5 m, and the deepest at approximately 13.0–14.0 m below the ground surface. At boreholes EXP1, EXP4, and EXP6, five measurement levels were installed at depths of 4 m, 8 m, 12 m, 16 m, and 20 m below the ground surface. Some measurement levels of extensometers EXP3, EXP5, and EXP6 recorded upward movement several metres before the passage of the crown. The most significant uplift was recorded at extensometer EXP5, where an uplift of +12 mm was measured at a distance of 4 m ahead of the crown. These movements were caused by the application of systematic pressure grouting of the micropile umbrella carried out in front of the crown face. Following the passage of the crown and the core beneath the monitoring profile, a loosening phase occurred. Approximately 12 m after the passage of the crown and the core beneath the extensometer borehole, gradual stabilization of deformations was observed. The remaining extensometers responded to the tunnelling advance with the expected settlement. Settlement values ranged from −9 to −46 mm. The highest absolute settlement value was recorded at extensometer EXP5, where deformation reached −31 mm at the deepest anchor and up to −56 mm at the shallowest anchor (Fig. 6).

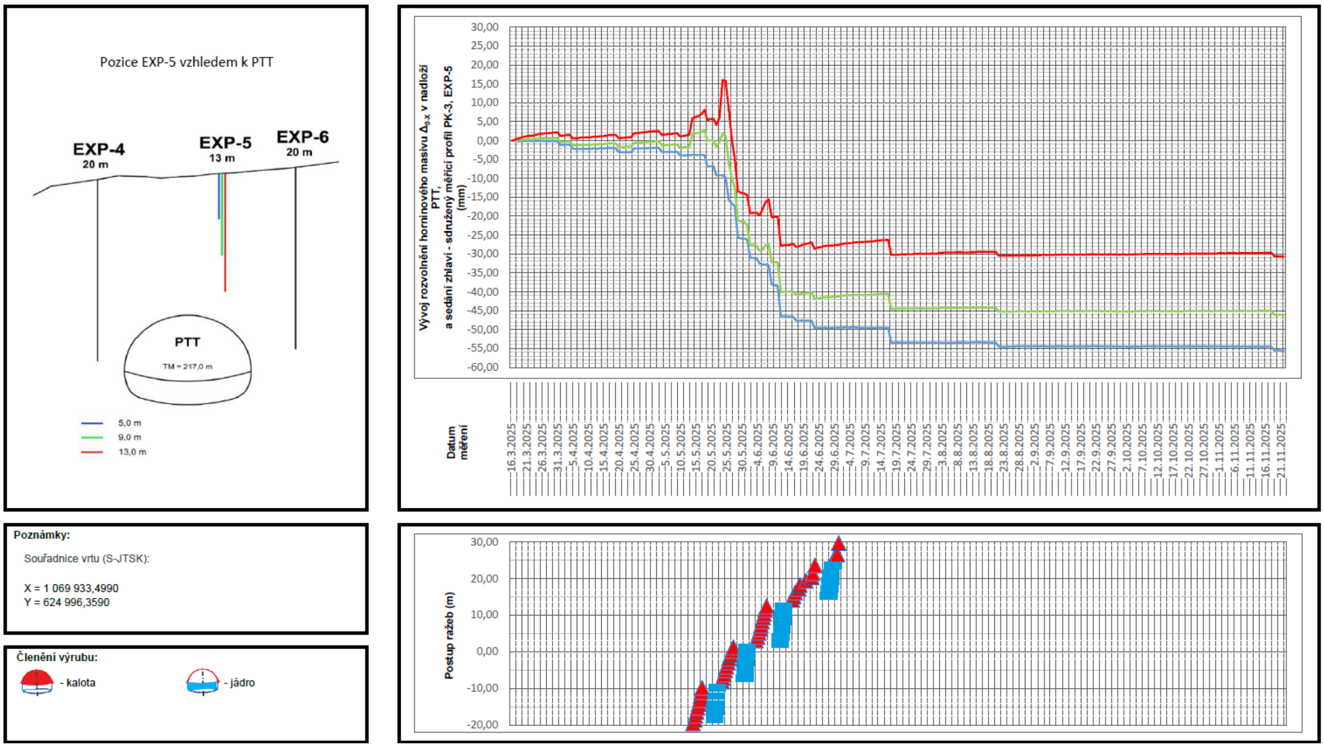

Figure 6: Deformation curve of the EXP-5 extensometer.

3.3 MEASURING THE STRESS ON THE PRIMARY LINING

During tunnelling, stresses in the primary lining were also monitored. Vibrating wire strain gauges were used to measure stresses in the primary lining. A total of five monitoring profiles were installed, each consisting of five pairs of strain gauges (Fig. 7). The strain gauges were always installed in pairs on the intrados and extrados of the primary lining, oriented in the direction of the expected maximum normal stresses. The maximum measured stress values ranged from 15 to 20 kPa, in compression or tension.

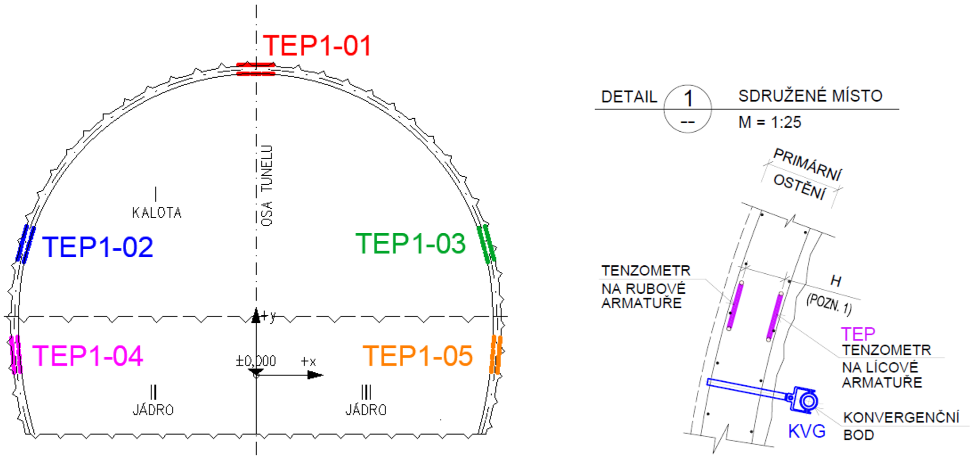

Figure 7: Position of strain gauge placement in the measurement profile TEP-1.
Detail of the position of strain gauges on the back and front sides of the primary lining reinforcement.

3.4 MEASUREMENTS AT PORTALS AND EXCAVATION PITS

Within this scope of activities, geotechnical monitoring of the stability of the portal retaining structures and tunnel excavation pits was carried out using measurements of trigonometric points, dynamometers, and inclinometer surveys. In total, 23 trigonometric points and 10 dynamometers installed beneath the heads of ground anchors were mounted on the retaining structure in the area of the western portal. In the area of the eastern portal, 30 trigonometric points and 12 dynamometers were installed. In addition to the above-mentioned monitoring elements placed directly on the geotechnical structures, continuous monitoring of adjacent slopes was performed using inclinometer boreholes, which had been constructed during individual stages of engineering geological investigations as well as during tunnel construction. Overall, subsurface deformation monitoring was provided by five inclinometer boreholes at the western portal and six boreholes at the eastern portal, distributed around the perimeter of the portal wall and in the initial metres of the mined tunnel tubes.

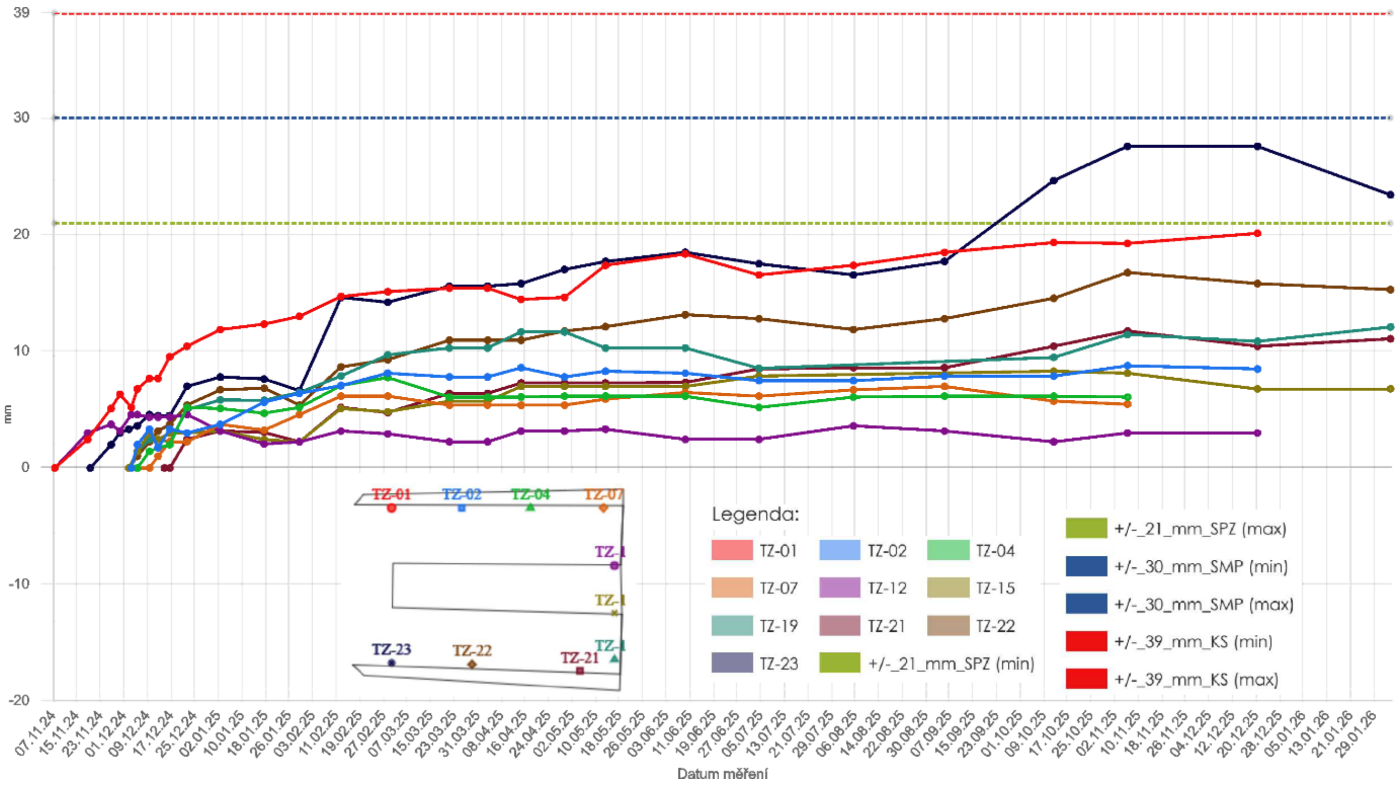

Figure 8: Development of deformations of trigonometric points installed on the walls of the western portal.

Excavation of the portal construction pits did not result in any significant deformations of the portal slopes or the structures themselves that would be demonstrated by geotechnical monitoring, and the entire structure was therefore constructed under a high level of safety. Deformation values measured in the excavation pits at the western portal ranged from 4.0 to 20.15 mm (Fig. 8). The highest deformation values were detected at point TZ23 (27.5 mm), where the first warning level (21 mm) was exceeded. In the area of the eastern portal, deformation values ranged from 1.40 to 12.65 mm. At these points, the warning state criteria were not exceeded.

The development of anchor forces measured using dynamometers fully reflected the progress of works in the portal sections. Anchor forces in the area of the western portal ranged from 570 to 803 kN. In the area of the eastern portal, anchor forces ranged from 223 to 857 kN, depending on the type of strand anchor used. Increases in anchor forces were mostly associated with construction activities on the portal walls and in their immediate vicinity.

3.5 HYDROGEOLOGICAL MONITORING

The hydrogeological monitoring carried out in 2025 in connection with the construction of the D35 motorway between Ostrov and Vysoké Mýto provided comprehensive information on changes in the groundwater regime, particularly in the area of the Homole tunnel. The monitoring network comprised 17 hydrogeological boreholes equipped with continuous groundwater level sensors, six household wells, and supplementary measurements on surface watercourses and springs. This configuration enabled detailed tracking of temporal groundwater level dynamics and their response to ongoing construction activities. The monitoring results reveal pronounced spatial differentiation in the hydrogeological response. Boreholes located in the immediate vicinity of the tunnel or within its hydraulic influence zone exhibited significant groundwater level declines following the start of excavation, typically ranging from several metres to several tens of metres. These changes occurred over a relatively short period and resulted in the establishment of a new, stabilized groundwater regime with minimal fluctuation amplitude, confirming the long term drainage effect of the tunnel on the Cretaceous aquifer developed within variably fractured marlstones and siltstones. Conversely, boreholes situated at greater distances or in areas affected only by surface construction activities showed no clear anthropogenic influence; groundwater level development in these locations continues to reflect natural climatic and seasonal factors. The findings to date clearly confirm that the Homole tunnel excavation represents a major impact in the deeper groundwater system in the location of the tunnel. At the same time, the predicted absence of impacts on water sources in the medium distance surroundings has been validated, including the well known spring near the Church of St. Nicholas in Vraclav, traditionally attributed with healing properties. The long term evolution of hydrogeological conditions after completion of the Homole tunnel, including its permanent drainage system, will be of considerable interest.

4. CONCLUSION

From the perspective of geotechnical monitoring, the excavation of the Homole Tunnel, which forms part of the D35 Ostrov–Vysoké Mýto motorway, represented an interesting challenge that required thorough and intensive preparation as well as effective implementation. The geotechnical monitoring carried out by the Contractor played an important role in this project and, thanks to its high-quality design and execution, successfully fulfilled its function throughout the entire construction period. Based on the monitoring results, it can be concluded that the deformation behaviour of the primary lining was maintained within the limits defined by the design. The primary lining of the tunnels was robustly designed, including the use of pressure grouting of micropile umbrellas. Individual excavation rounds in geologically demanding conditions with low overburden were short, mostly with lengths of up to 1 m. The greatest concerns were associated with tunnelling beneath the heavily trafficked Road I/17. Exceedance of warning levels at the surface was recorded only in the area of ground settlement within the settlement trough outside the alignment of Road I/17. During monitoring of the road surface of Road I/17 itself, warning levels were exceeded only locally. The maximum pavement settlement stabilized at a value of −41 mm. Despite these facts, traffic on the road was not restricted. An assessment of the construction process to date indicates that the effective use of geotechnical monitoring data is the result of close and proactive cooperation between the geotechnical engineers and geologists on both the contractor’s and the client’s sides, as well as, of course, between the designer and the contractor.

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