

GEOTECHNICAL MONITORING DURING THE CONSTRUCTION OF BARRIER-FREE ACCESS TO THE JIŘÍHO Z PODEBRAD METRO STATION

M. Čermák, B. Pavelková, R. Morávek
INSET s.r.o., Prague, Czech Republic

ABSTRACT: The barrier-free access to the Jiřího z Poděbrad metro station on line A is a major infrastructure project implemented in a densely built-up part of Prague. The construction of new elevator shafts and underground corridors was connected to the existing metro station structure and took place in the vicinity of utility networks and buildings, in particular the Church of the Most Sacred Heart of Our Lord by architect Josip Plečnik. The demanding construction conditions required detailed geotechnical monitoring and its continuous evaluation. The monitoring included measuring deformations of the station lining, surface shifts and subsidence, monitoring deformations of adjacent structures, and monitoring the stress-strain state of the rock mass during excavation. The measured values were continuously compared with predictions from numerical models and were used to verify the assumptions of the project documentation and to modify technological procedures. The work also included monitoring of the engineering-geological conditions characterized by cracked Letná shales in the vicinity of the metro station. The paper summarizes the course and results of the monitoring, presents the values achieved for selected variables, and evaluates their relationship to the limits set by the project. Special attention is paid to monitoring the deformations of the Church of the Sacred Heart of Jesus, which was a key object in the entire area in terms of cultural value and static sensitivity. The monitoring demonstrated the effectiveness of the measures taken and confirmed the suitability of the selected technological procedure for the construction in demanding urban conditions.

1. FOREWORD

This article loosely follows on from an article published in *Tunel* magazine (ČERMÁK, M., PAVELKOVÁ, B., MORÁVEK, R., 2024), which dealt generally with geotechnical monitoring during the construction of barrier-free access to the Jiřího z Poděbrad metro station and did not include specific measured values. Apart from a textbook-like graph from automatic extensometric measurement (automatic measurement of the distance between the drill head and individual anchor levels, supplemented by geodetic measurement of the drill head settlement), no graphical outputs of the measured data were provided.

This article then presented in detail the measurement of dynamic effects with regard to objects and persons, the differences between these measurements, and their evaluation. Furthermore, the article sought to present certain reflections on the topic of geotechnical work according to Decree No. 55/1996 Coll., about which only basic information is provided in the decree itself. So far, no relevant document has dealt with this activity in more detail within the meaning of the aforementioned decree. The general requirements for the work of a geotechnical engineer are very well presented in TP-237 of the Ministry of Transport from May 2011, but these were created before the amendment No. 265/2012 Coll. to Decree No. 55/1996 Coll. in 2012, and therefore do not include the activities of a geotechnical engineer according to Decree No. 55/1996 Coll. therefore do not include the activities of a geotechnical engineer.

2. INTRODUCTION

The project itself and the experience gained from the construction of barrier-free access to the Jiřího z Poděbrad metro station have already been presented in two articles (KOREJČIK, J., ŽIŽKA, Z., KOLEVSKI, M., 2023) and (VELIČKA, P., PANUŠKA, J., 2025) in *Tunel* magazine, and detailed information is not provided here. In this article, we expand on the previously presented information on monitoring and publish specific measurement results for selected methodologies. At the end of the article, there is a

summary of the measured values, including warning conditions, which were determined by the designer or a court expert, who also determined them on the basis of the carried-out passportization.

3. GEOTECHNICAL MONITORING

Work on geotechnical monitoring began in May 2021 with the registration of structures in the affected zone, and forensic expert reports were gradually prepared for these structures, specifying their deformation and dynamic resistance. Before excavation and tunneling began, observation wells were also drilled for extensometric, inclinometric, and hydrogeological measurements.

During construction, geological and geotechnical documentation of the excavation and tunneling sequence was carried out, with individual tunneling sections classified into NRTM technological classes. This was done according to engineering-geological documentation, geomonitoring results, and visits by a geotechnical engineer to the tunnels, primarily during the mechanical breaking of rock. The deformation behavior of the primary lining, sewer tunnels, station tunnels, and the central station hall of the metro (convergence) was monitored. Furthermore, strain gauges were used to monitor the stress in the steel frame located at the interface between the shaft and the breakout at the platform level. The dynamic effects of blasting and expansion breaking, i.e., the use of pyrotechnic products for technical purposes, were also monitored. Levelling was then measured both on the structures and on the terrain above the excavations, and one dynamometer was installed as part of the excavation of the construction pit. During the construction work, complaints from owners and residents of the surrounding buildings about the damage caused were also dealt with – in the vast majority of cases, these were old damages, also with regard to the passportization carried out. In one of the buildings, which was located outside the subsidence basin (the designated zone of influence) and the isoseismal line of 5 mm/s, measuring devices were installed following a complaint. The results of the deformation measurements showed temperature effects and no impact from the construction work. Measurements of total vibrations (impact on humans) led to the conclusion that only three rock break-ups per day could be performed.

3.1 CHURCH OF THE MOST SACRED HEART OF OUR LORD

The Church of the Most Sacred Heart of Our Lord (Figure 2) was monitored using a number of methods as an important cultural monument.



Figure 1: Distribution of measuring points from different methodologies and the zone of influence from the project documentation (see also the situation in (ČERMÁK, M., PAVELKOVÁ, B., MORÁVEK, R., 2014))



Figure 2: View of Jiřího z Poděbrad Square – in the foreground, the construction of barrier-free access, and behind it, the Church of the Most Sacred Heart of Our Lord (source: <https://earth.google.com>, as of June 11, 2023)

In accordance with the geotechnical monitoring proposal, the following measurements were taken:

- settlement at 11 leveling points located around the perimeter of the church (Figures 3 and 4),
- positional deformations at a total of 20 points set up from a lifting platform and climbing on the shell of the building and especially the tower (always two points above each other),

- changes in crack width at a total of 35 locations (mainly as uniaxial measurements between two points),
- dynamic effects from blasting and expansion cutting (use of pyrotechnic products for technical purposes).

Following a proposal by the geotechnical monitoring contractor and after multilateral agreement among the members of the monitoring council, the above measurements were gradually supplemented during construction by automatic measurements (with readings taken every 10 minutes), which also partially replaced manual readings at the measuring points:

- measurement of changes in crack width at 12 points,
- church tilt at 4 locations, mainly in the church tower.

Based on negotiations with the district mining authority regarding blasting work, the parish's request was accepted and the above was supplemented during construction by:

- regular inspections and processing of the part of the church adjacent to the construction site, in particular the tower, at intervals of once every 14 days,
- processing of the results of measurements and inspections for the parish once a month.

From the measurements taken and their development (Figure 3), it is clear that even the first warning level was not exceeded by a sufficiently large margin (see Table 1). The highest settlement value was near the excavations, i.e., the southeast corner of the church, which was in line with expectations. For this reason, a higher number of monitoring elements was proposed for this area. Figure 4 shows the settlement isolines at the end of the measurement. The measuring points, together with the data transmission equipment, were also selected with regard to the operation of the church itself and to avoid significant interference, such as from visitors walking around. An example of the installation is shown in Figure 5 and the measurement results in Figure 6.

The measured changes in crack widths from automatic measuring devices in the church were not significantly affected by temperature. At the same time, no significant correlation with construction activity was measured. The measured values were well below warning levels – see Figure 6 and Table 1. Simultaneously with the measurement of crack width changes, the temperatures of the measured structure were also measured at these locations. Figure 6 shows how the church tower is significantly affected by temperature changes, and the maximum and minimum temperatures were measured at the same time at a point in the tower (shown in red in the graph).

An article in *Tunel* magazine (ČERMÁK, M., PAVELKOVÁ, B., MORÁVEK, R., 2014) presented a cross-section showing the deformations of the church towards the building structure, based on measurements of positional points on the facade of the building. In Figure 7, we supplement this with deformations in the floor plan, which correspond to the settlement of the building in Figure 4 and show deformations towards the station's transfer corridor, i.e., there was uneven settlement and tilting of the church towards the excavations.

By measuring the positional points on the church facade and measuring the automatic inclinations (after compensating for the influence of temperature on the measured values), similar inclination curves towards the building were found. The inclination of the church was presented both in relation to the terrain and as the difference in deformation values from points above each other, which eliminated some measurement errors and made the graphs significantly "smoother" and the reported deformations smaller. The maximum measured and calculated values with warning conditions are listed in Table 1.

During the inspections carried out in the church, new cracks were documented, but these were more likely cracks that commonly occur in connection with annual temperature fluctuations and the drawing of older cracks, which were only painted over or were in places where they could not be associated with the construction work being carried out. The temperature fluctuations themselves are significant in the church – see the temperature measurements taken by automatic deformometers, which show differences of up to 30 °C or even higher (measured over less than two annual cycles). Due to the temperature, the most significant damage occurred in the area where the ramp railings are anchored, which are located in

the tower at the level of the glass clock – similar damage gradually began to appear to a lesser or greater extent in other parts of the ramps (Figure 8).

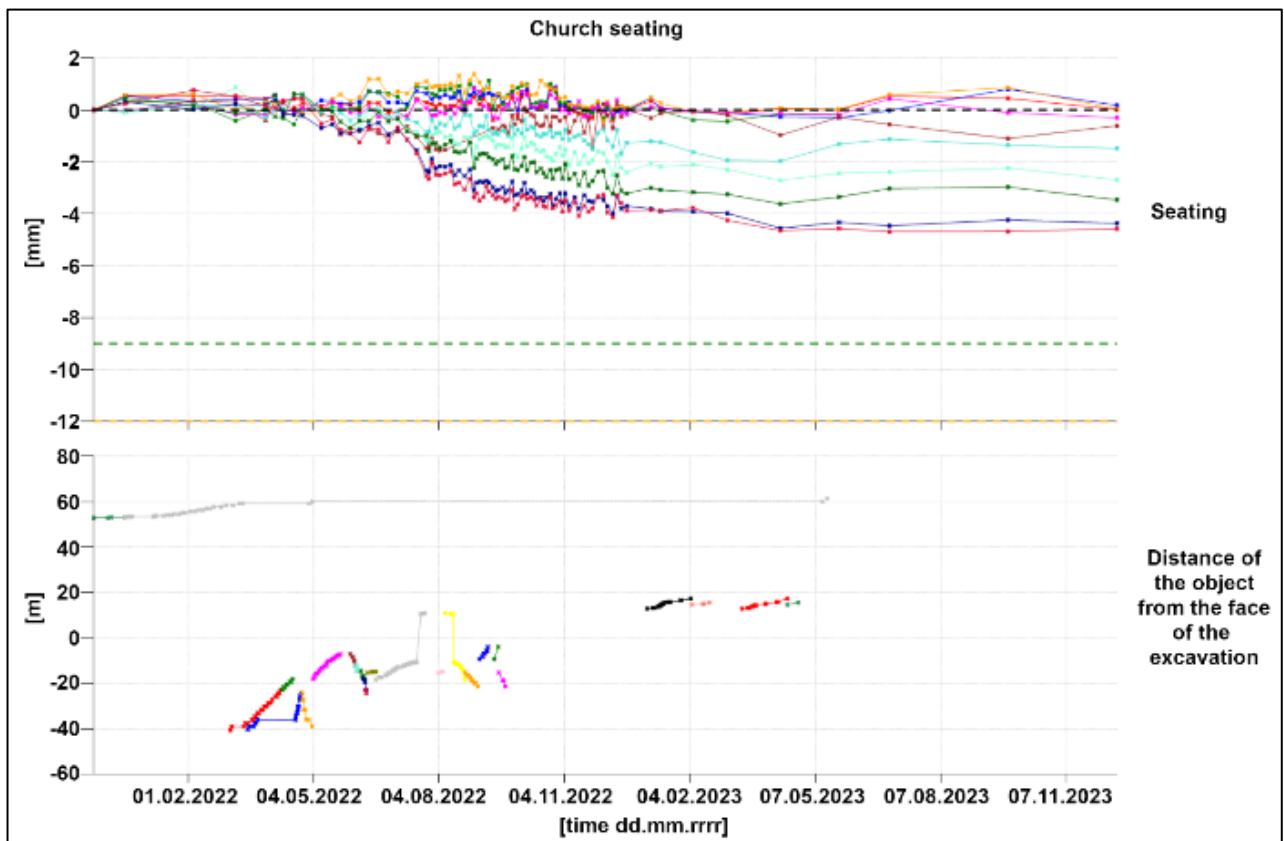


Figure 3: Settlement of the church depending on the execution of excavation and tunneling

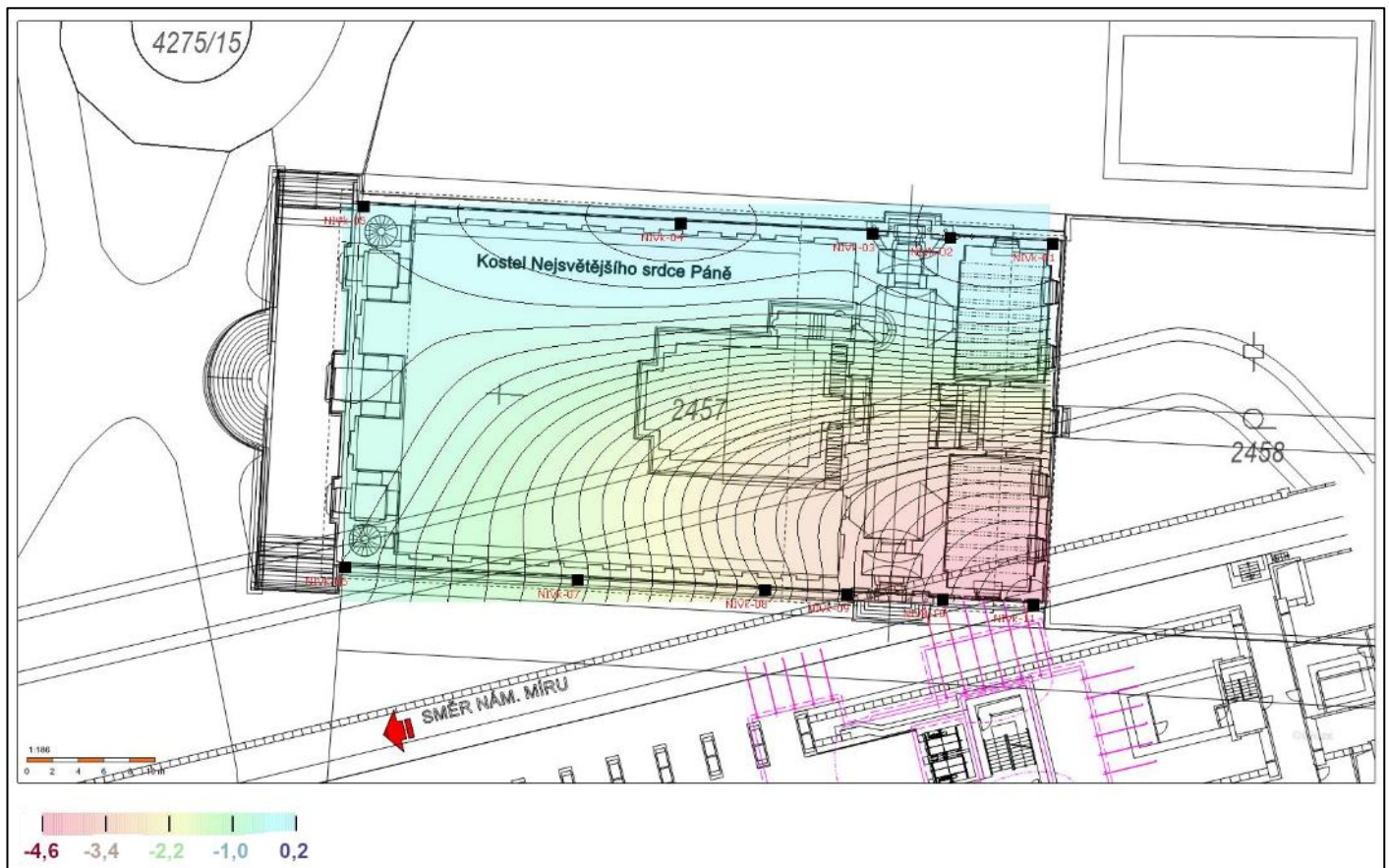


Figure 4: Contour lines showing the settlement of the church at the end of the measurement (on December 14, 2023)



Figure 5: Automatic crack width measurement device with electronics for sending measured data to the geotechnical monitoring office (glued to the structure)

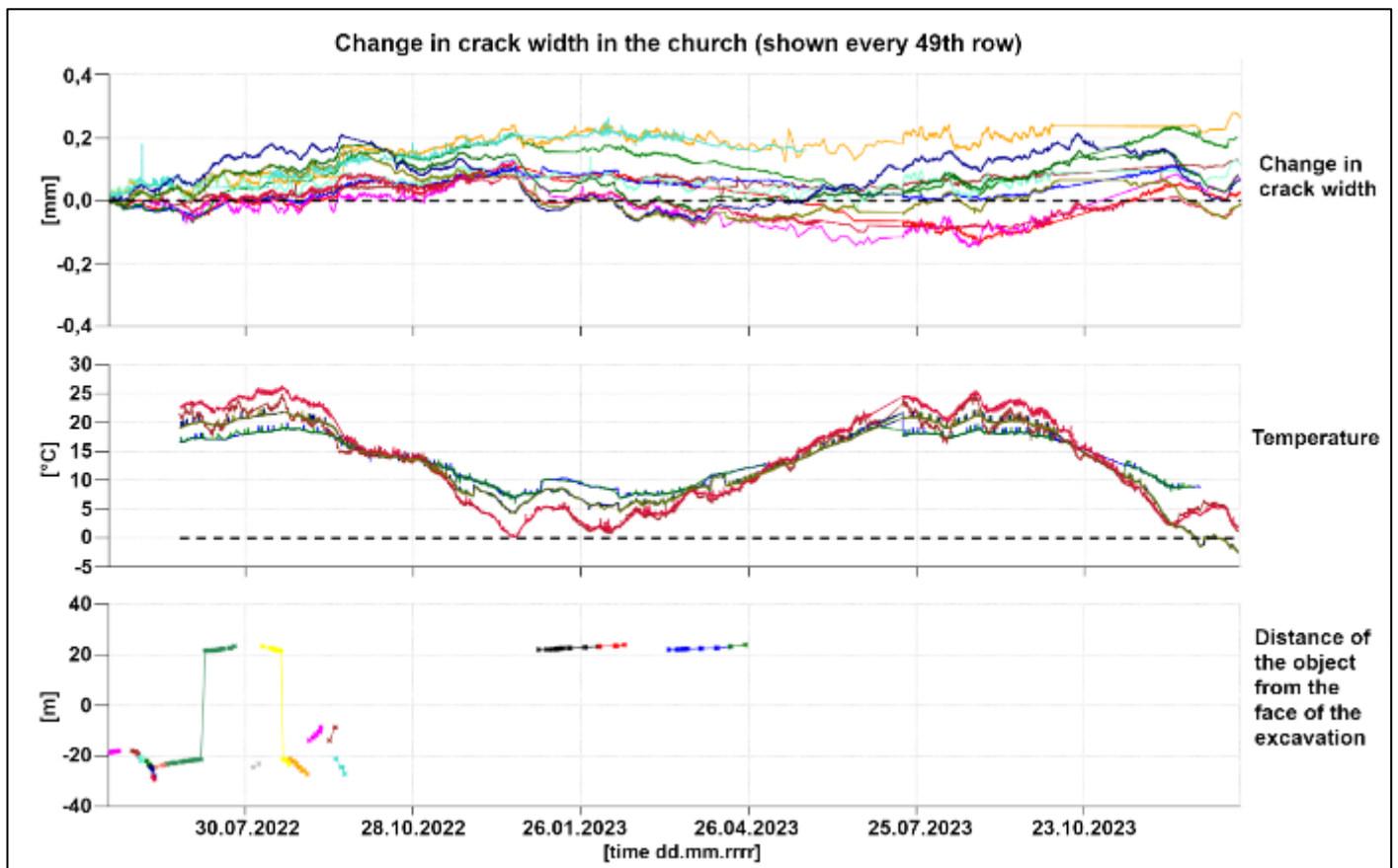


Figure 6: Measured changes in crack widths in automatic mode, measured temperatures for individual gauges, and construction progress



Figure 7: Fans showing the direction of deformation at positional points on the church facade (always two points above each other, inclination relative to the terrain)

After the measurements were completed, all areas where the structure had been altered due to the installation of measuring points were repaired by a specialist company that had already carried out repairs on the church. This involved the use of materials and colors approved by the Department of Monument Preservation and the parish – this mainly concerned the holes left by the points in the mortar between the bricks on the facade. This restoration work was first carried out by an employee of an external company from a platform and then, after instruction by our employees, by climbers on the tower.

3.2 TERRAIN SETTLEMENT IN THE AFFECTED ZONE

Figure 9 shows the contour lines of terrain settlement from the leveling points. The area where the greatest subsidence occurred corresponded to the most demanding excavation sites, namely above the transfer corridor from which excavations were carried out towards and from the church and the excavation of the shaft connecting the transfer corridor level and the platform level.



Figure 8: Damage at the point of attachment of the ramp railing due to temperature

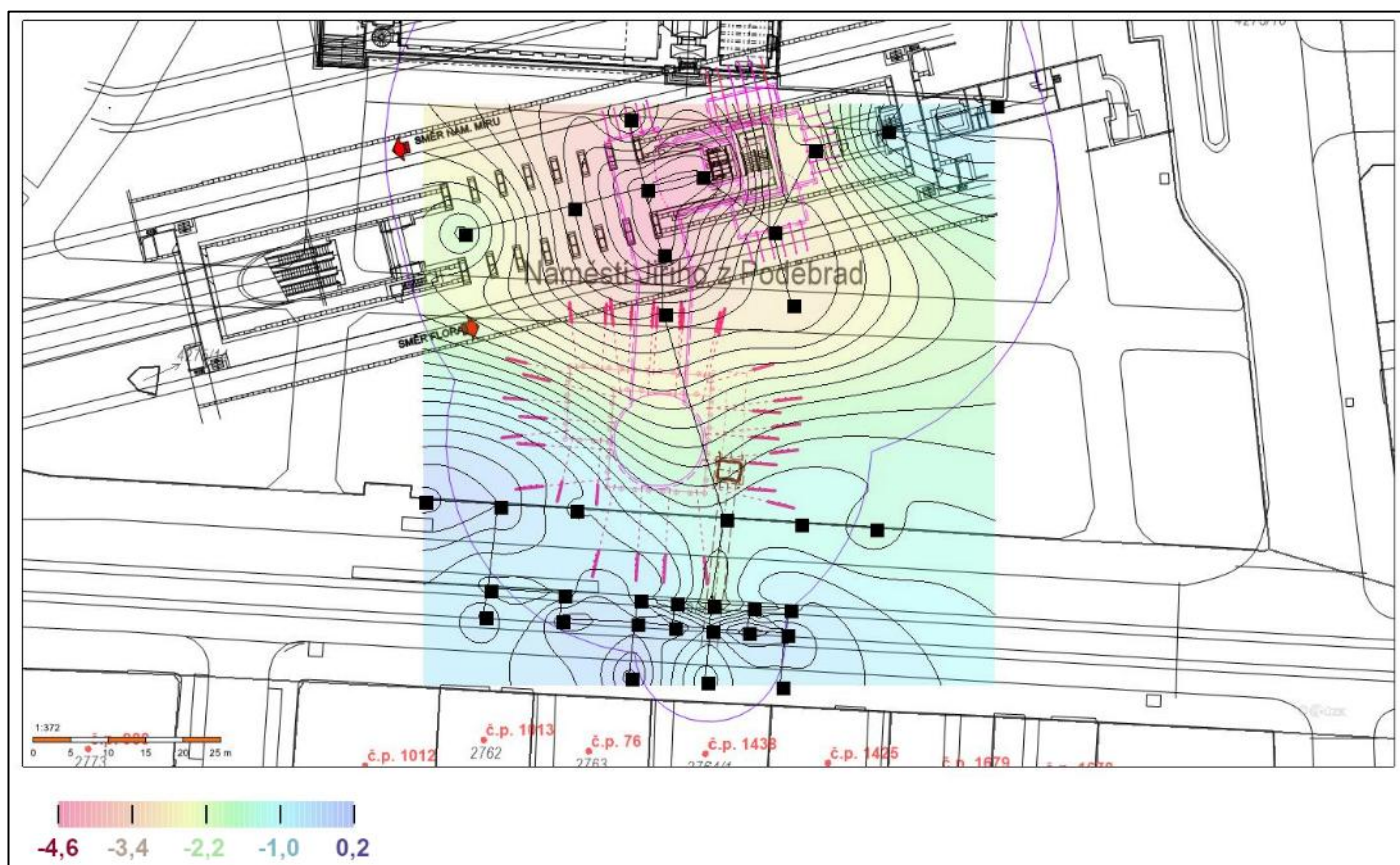


Figure 9: Contour lines of terrain subsidence at the end of the measurement (on May 13, 2024)

The maximum measured values of settlement and uneven settlement, together with warning conditions, are shown in Table 1.

Table 1: Measured values on measuring elements in the church and in the field

object	measurement	measured	warning status A
church	leveling	4,7 mm 1:5168	leveling: 12 mm uneven settling: 1:500
	crack width - manual meas.	-0,71 / 0,58 mm	crack width: 5 mm
	crack width - automatic meas.	-0,15 / 0,27 mm	
	3D points		changes to 5,3 mm (leveling), 4,8 mm (horizontal direction)
0,61 (inclination by calculation - relative to the terrain)			inclination: 0,5 mm/m
0,36 (inclination - points above each other)			
surfaces (terrain)	leveling	9,3 mm 1:1078	leveling: 15 mm uneven settling: -

3.3 INCLINOMETRIC MEASUREMENT

In the area between the church and the excavations at the level of the transfer corridor, an inclined borehole was drilled together with other boreholes (an extension borehole and two hydro boreholes) before the start of construction work, in which horizontal deformations of the rock environment were subsequently monitored.

The location of the borehole had to be adapted to the presence of a water main, and the depth of the borehole was terminated above the station tunnel. The left part of Figure 10 shows the total horizontal deformations as sums relative to the fixed base of the borehole. Due to the progress of shaft excavation and tunneling at the platform level, these were no longer measurements with a fixed base.

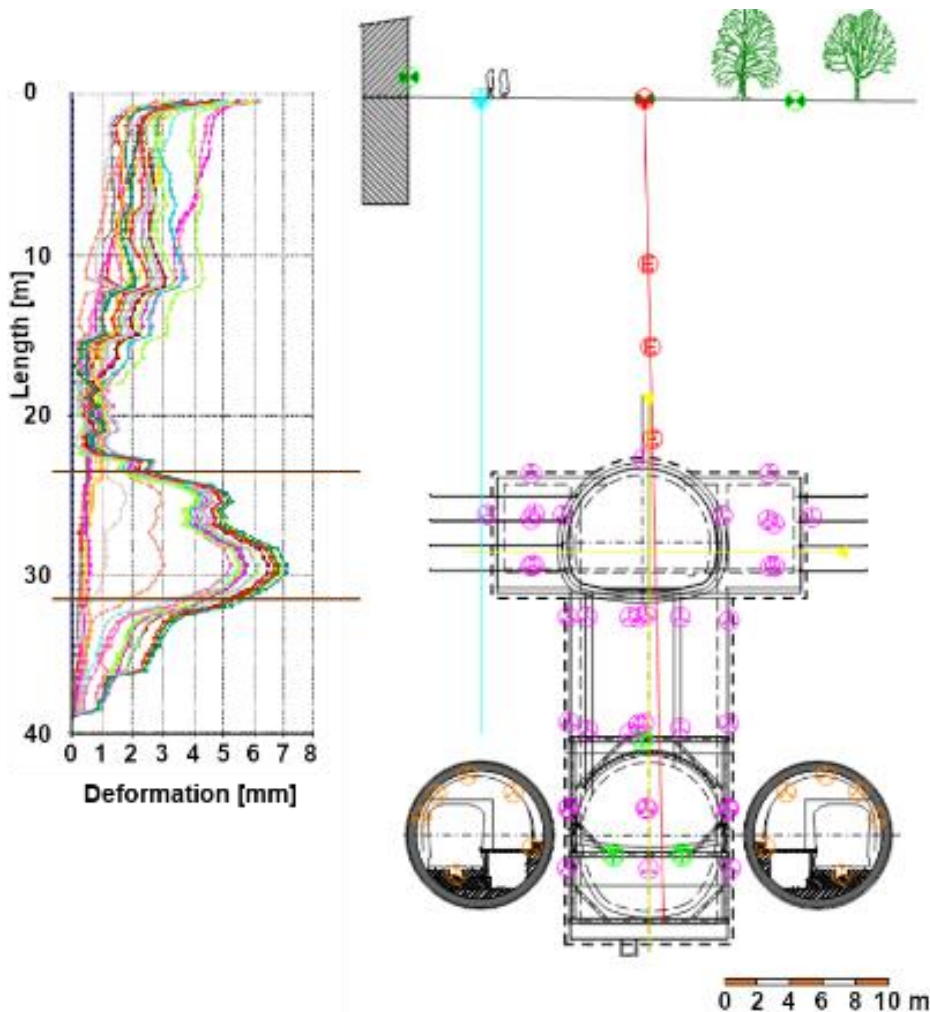


Figure 10: Measurement results in the inclinometer borehole – on the left, the deformation vector corresponding to this section, and on the right, a section from the Sahure information system (borehole shown in turquoise).

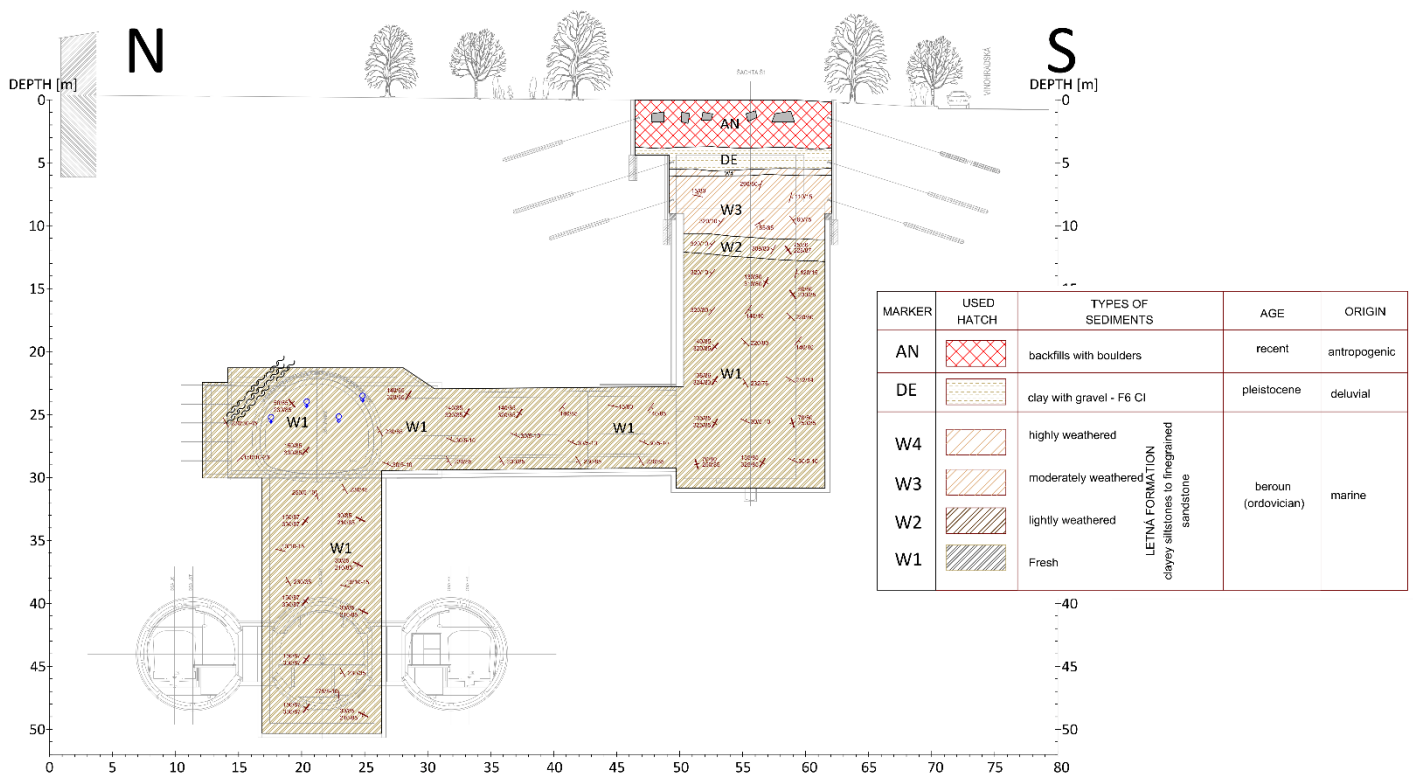
3.4 GEOLOGICAL DOCUMENTATION

The outputs from the geological documentation were processed in west-east and north-south geological sections (Figure 11) instead of a classic mining map, taking into account the structure of the excavation and tunnelling.

During the excavation of shaft Š1, layers of fill containing concrete blocks up to one meter in size were first encountered. Beneath a layer of deluvial clayey soil, rocks of the Letná Formation were encountered. The excavation of the access tunnel began from shaft Š1 at a depth of 30 m. The access tunnel first ran 41 m northward, then 22 m eastward. From the base of the access tunnel, shaft Š2 (14 m) was then excavated, running between the metro tunnels to the level of the platform in the area outside the station. From shaft Š2, 8 m was then excavated westward to the station. During excavation, only minor groundwater inflows were encountered, apparently associated with a fault zone (see Figure 11). The groundwater level was encountered below the level of the existing metro base in the Letná shale fracture system.

The rock mass was evaluated according to Tesař's classification, and the excavation was subsequently classified into NRTM classes. The quality of the massif from a depth of 30 m was rated 53-60.5 QTS points. In areas with tectonic rock disruption accompanied by moderate groundwater inflows, the point rating was reduced to 45.5 points due to the introduction of β and γ reductions. Degraded rock encountered during the excavation of the tunnel at the platform level was rated 40.5 QTS points.

Compared to the exploratory work, the excavation revealed higher rock strength, which approached 50 MPa in the sandy locations of the Letná Formation. The rock mass in healthy Letná shales showed discontinuities up to one meter apart with a distinctive block structure caused by a system of three perpendicular planes of separation. The rock mass around the metro station (built in the late 1970s) was degraded due to blasting work. The degradation manifested itself in the discoloration of the rock, reduced strength, limonite coatings on discontinuities, and a reduction in the distance between discontinuities (2-3 times) to a distance of 2-3 m from the original extent of the excavations. The nature of this degraded rock mass was verified by pressure tests from a fan of boreholes drilled from the metro station.



4. CONCLUSION

The construction of barrier-free access to the Jiřího z Poděbrad metro station has made it one of 47 fully barrier-free stations in the Prague metro system. The newly established barrier-free access allows passengers smooth access from street level to the platform via a transfer corridor equipped with two pairs of elevators. The construction work included geotechnical monitoring, which began in advance of the actual construction. Due to the station's location in close proximity to a national cultural monument, the Church of the Most Sacred Heart of Our Lord, and other buildings, it was necessary to carry out comprehensive monitoring of these structures.

The Church of the Sacred Heart of Jesus was the most monitored above-ground structure during the excavation (and, apart from the effects on the structures on Vinohradská Street, practically the only one).

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Title, first name, last name of author: Ing. Martin Čermák

Workplace: INSET s.r.o.

E-mail address: cermak.martin@inset.com

Title, first name, last name of author: Ing. Barbora Pavelková

Workplace: INSET s.r.o.

E-mail address: pavelkova.barbora@inset.com

Title, first name, last name of author: RNDr. Radek Morávek, Ph.D.

Workplace: INSET s.r.o.

E-mail address: moravek.radek@inset.com