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PROVIDING STABILITY TO A HIGHWAY CUT IN A LANDSLIDE AREA WITH THE USE OF DIAPHRAGM WALL PANELS

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Abstract. The route of the D1 highway in the Lietavská Lúčka - Dubná Skala section near Žilina is taken forward by a 17 m deep cut in a section about 300 m long. The first proposed solution of the highway route was based on the assumption that it is a stable area. However, during the construction of the highway cut an old landslide area with a depth of shear surfaces of up to 25 m was identified right in the area of the cut. Therefore, massive measures had to be designated to assure that the area above the highway and the access to the tunnel portal were not threatened by landslides. When addressing the security of the cut, an unusual solution was used - anchored diaphragm wall panels of underground concrete walling oriented towards the slope. Currently, this given solution is under construction and is controlled by inclinometers incorporated into selected diaphragm wall panels.

Keywords: Anchors, landslide, concrete diaphragm walls, slope stability.

1. Introduction

Currently in Slovakia the most complicated sections of the D1 highway are under construction [1, 2]. Route D1 in central Slovakia near the regional city Žilina is one of them (Figure 1). The surface part of the D1 highway route in the section Lietavská Lúčka - Dubná Skala (outside the Višňové tunnel) is approximately 4.8 km long. The route D1 passes here through five landslide areas, and the largest landslide area in terms of surface area and depth of the sliding surface is at 3.795–4.80 km (Figure 2). In the section 4.5–4.8 km in front of the western portal of the Višňové tunnel, the highway route is led through a right-hand cut with a depth of up to 17 m and the aforementioned complicated landslide area.

With regard to the relatively extensive and deep landslide area, even if it is currently inactive, it was reasonable to assume that the 17 m deep cut would endanger the stability of the slope of the cut itself. However, not only the indicated slope of the cut would be endangered, but also a significant part of the area above it. There are at present inactive sliding blocks of claystones and limestone at a distance up to 250 m from the edge of the cut.

For the aforementioned reason, this had to be subject to massive measures to secure the slope, so there would be no movement that would progressively reactivate up the slope. This would endanger the part of the highway in front of the portal of the tunnel and thus also access to it.

In order to give stability to the cut, anchored diaphragm wall panels oriented towards the slope were used. This is an unusual solution, because underground walls are primarily used as a securing and sealing element in deep excavations and foundations of buildings either for temporary excavation support or as part of the permanent structure [4–7]. Currently, the construction of individual diaphragm wall panels is being carried out on the construction site, and the upper part of the wall is being dug out for the purpose of its multi-level anchoring.

2. Engineering-geological and hydro-geological conditions

The environment of the Carpathian Flysch generates complicated geological conditions. Often, coarse permeable layers (sandstone, conglomerate which are aquifers) with high uniaxial strength alter with weathered soft and plastic claystone, and in some places it is in combination with tectonics [8]. Such geological settings present positive conditions for development of slope movements in the form of landslides and block deformations [9, 10].

The landslide area through which the highway route passes has an extent of approximately 600×700 m. The development of the landslide area took place in the distant geological past. It was a tectonic uplift of the marginal parts of the basin and a subsidence of the basin itself, where our interest area on such a tectonic edge is located. Vertical movements caused the division of the Paleogene formation into several blocks. These began to slide towards the valley forced by gravity. Subsequently the Mesozoic limestone blocks lying in the higher parts of the slope also started to move. In such a way, two block fields have been formed with a NE-SW direction of movement and has created morphological terrace-like elevations on the slope (Figure 2 and 3).

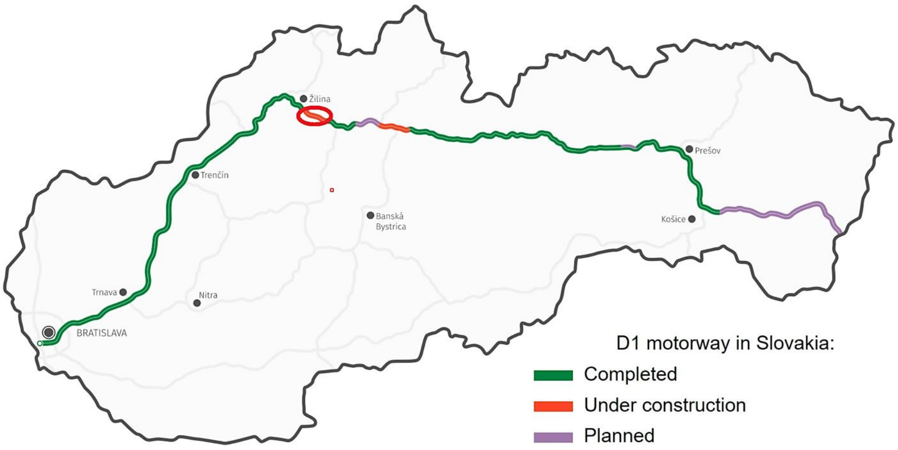

Figure 1. The route of D1 highway in Slovakia with indicated section of interest [3].

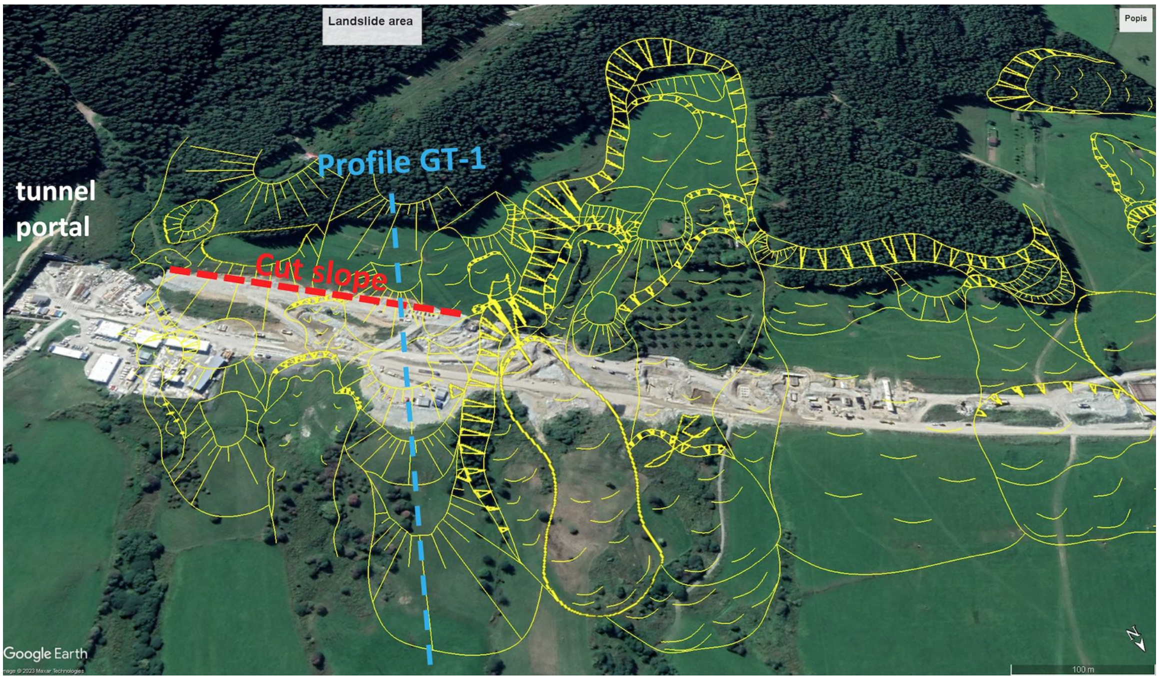

Figure 2. Landslide in front of the tunnel portal. The red line is the location of stabilization measures.

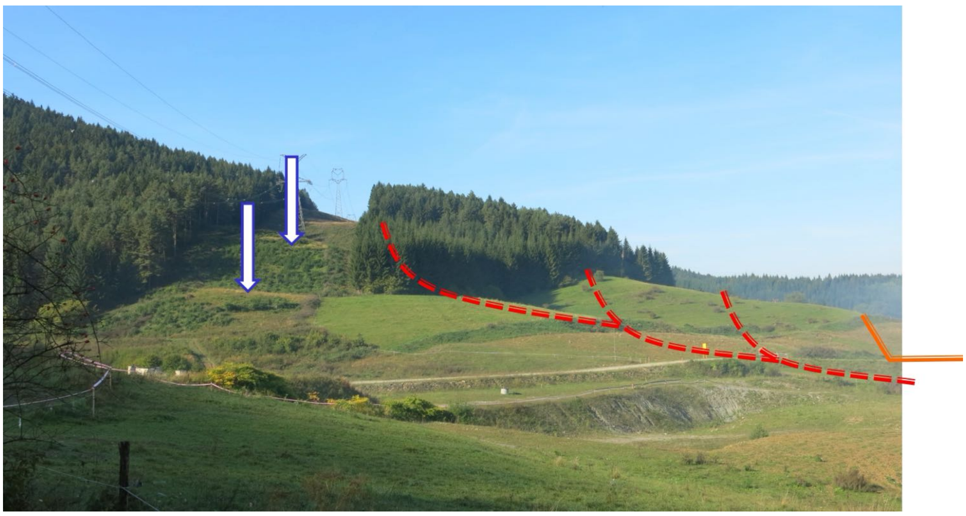

Figure 3. Distinct morphological blocks of rocks under the power line (blue arrows) and a diagram of blocks with shear surfaces (red lines).

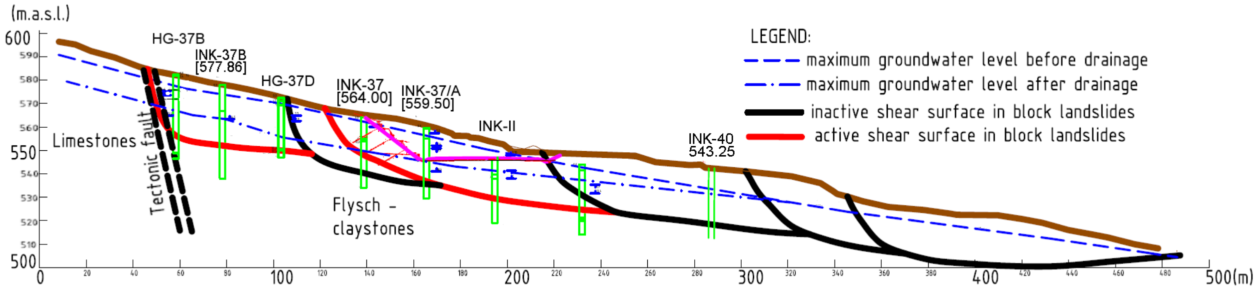

Figure 4. Engineering-geological profile of the landslide - model GT-1.

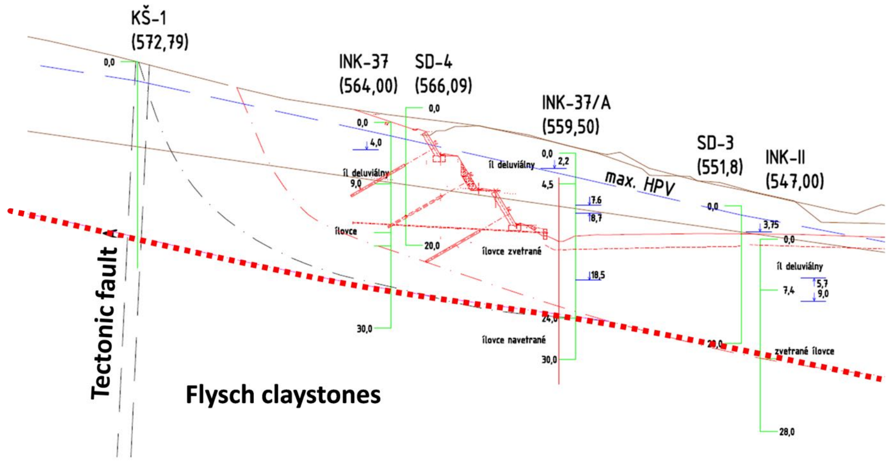

Figure 5. The design of the original solution from 2008 and its location in relation to the determined shear surfaces.

Evaluation of the investigation works (drilling and geophysical measurements) revealed that the landslide blocks of claystones can have a thickness of around 20–25 m (Figure 4). Important information was also provided by inclinometric measurements, which indicated a certain activity on the slopes. The movement of clay blocks before construction can be characterized as follows:

- There is a slow movement at a depth of 15–25 m, which, however, does not happen continuously.
- The movement vector is not always unambiguous.
- The movement has the character of tilting and rotation of blocks along a broader plastic zone.
- Groundwater plays a significant factor in the landslide area. It acts, both through a pressure effect but mainly by worsening the shear parameters in the disturbed zone.

The hydro-geological survey found several groundwater levels in the weathered and tectonically disturbed formation of claystone, siltstones and sandstone at depths of 1.6–18.5 m below the ground. The groundwater has an artesian character, which was manifested by its rise up to 10 m. In places where remediation works included horizontal drainage wells, the global groundwater level was reduced by up to 12 m. In the area outside of the reach of the horizontal drainage wells, a lowering of groundwater level was not recorded.

The above, together with a seismic risk in the given area (the city Žilina is located in an area where expected macroseismic intensity is up to 8th degree of MSK-64 scale), makes it clear that the entire section in question is a relatively complicated area for the construction of the highway.

3. Original solution for cut slope stability (period 2008–2019)

The very first measures for the stability improvement of the highway cut slope by the retaining wall were from 2008 as from the documentation for the building permit. The retaining wall was designed as a gradual, storey structure consisting of a system of concrete ribs, anchored with rope rock anchors with a length of 21.0 m. At that time, landslides were not considered and the anchors would clearly be insufficient, as can be seen from Figure 5.

It was only during construction in 2014–2019 that the presence of a landslide area was verified by mapping (Figure 2) and inclinometric measurements. In

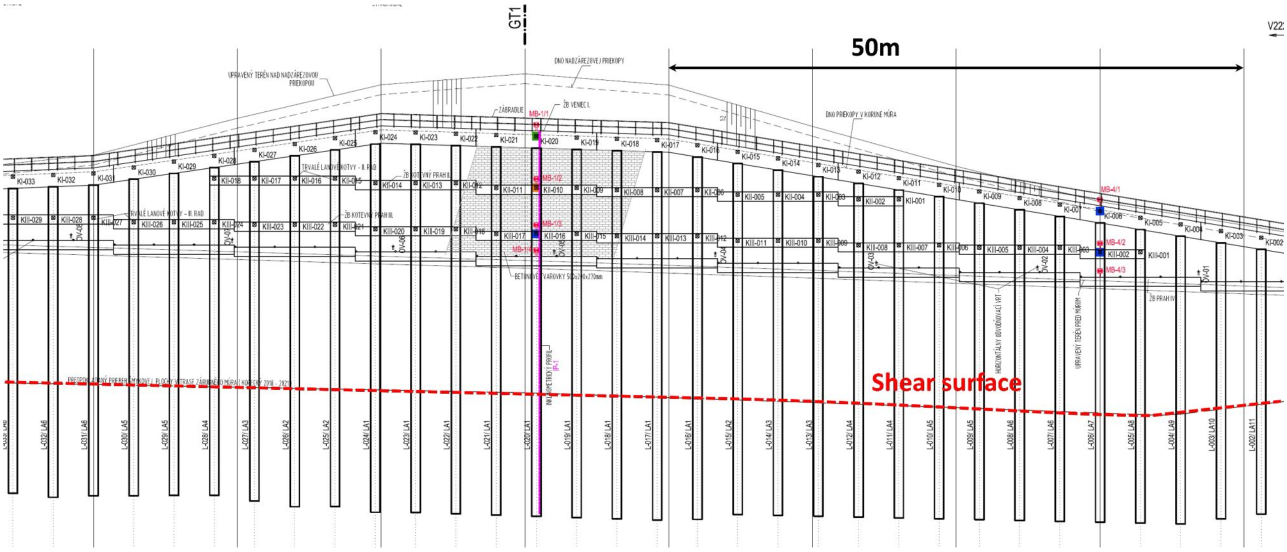

Figure 6. Part of the diaphragm retaining wall consisting panel elements in the section of GT1 model.

Figure 7. Excavation for the diaphragm wall panels with width of 2.8m.

Figure 8. Exposed panels with visible beams and anchors.

this period, however, the protection of the slope was not completed. The only conceptual proposal considered was for a possible protection in the form of anchored pile walls, when the piles reached a length of 30–35 m and the anchors about 50 m.

It was only after a change of construction contractor in 2021 that permanent stability measures were actually proposed.

4. The new proposed remediation works for the permanent highway cut slope stability (year 2021–2023)

During the works on new design of remediation measures of slope stability, various shapes and supporting elements of the entire structure were proposed:

As the most optimising design of the structure, segments of diaphragm wall panels of 2800 × 800 mm rotated by 90 degrees were chosen, and where the longer side is perpendicular to the route of the diaphragm wall. The axial distance of these segments is 3500 mm. Altogether, depending on the terrain configuration and the minimum necessary embedment under the shear surface, there were 81 designed diaphragm wall panels with a length of 25.0–32.0 m (Figure 6). Perpendicular rotation of the diaphragm wall panels is extremely important for the high rigidity of the structure and the transfer of bending moments. For the design of the structure, 3 characteristic geotechnical models GT1 (Figure 4), GT2, GT3 were created. These models were based on long established and refined engineering geological work and monitoring. Inclinometers for measuring deformations were built into selected diaphragm wall panels and dynamometers were installed into selected anchors.

- Piles DN 1200 mm in two rows with 4 rows of anchors,
- piles DN 1500 in two rows alternatively anchored with 4 rows of pile,
- diaphragm wall panels, etc.

Construction of the diaphragm wall panels was carried out by a combination of excavation by a cable grab to the level of 7.0 m and afterwards an excavation to the designated depth conducted by a hydrofraise

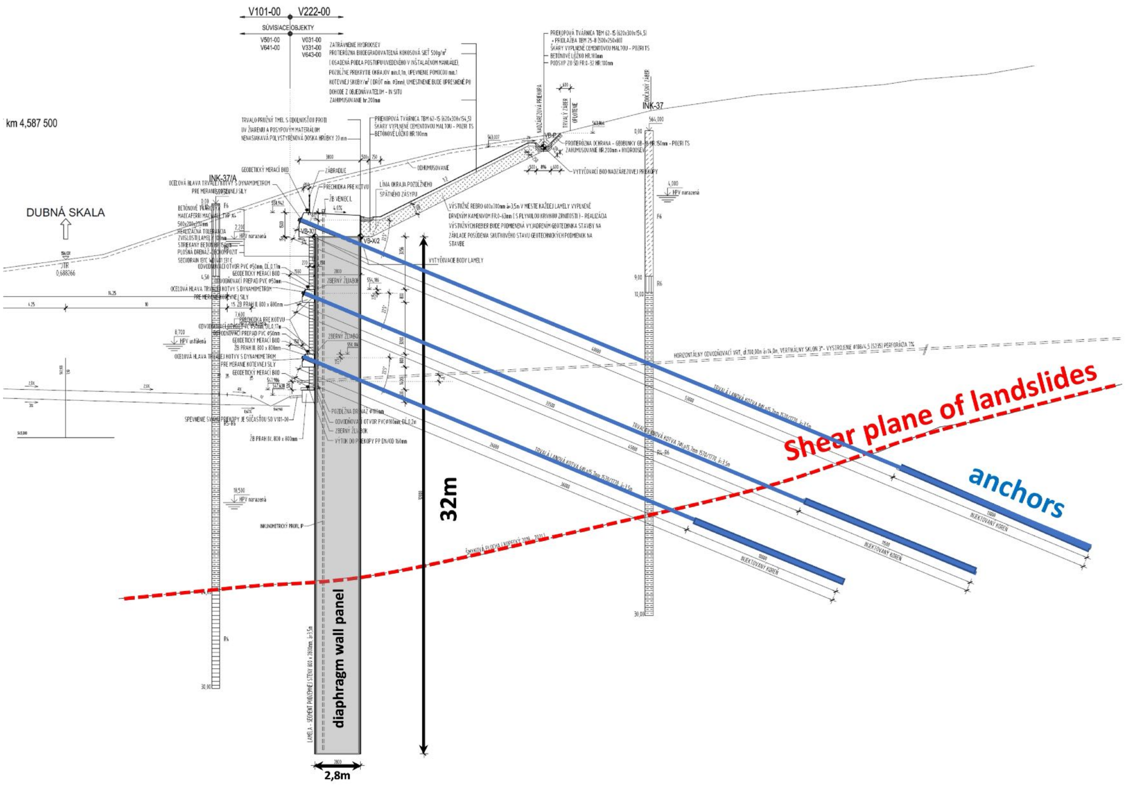

Figure 9. Wall cross-section of geotechnical model GT1.

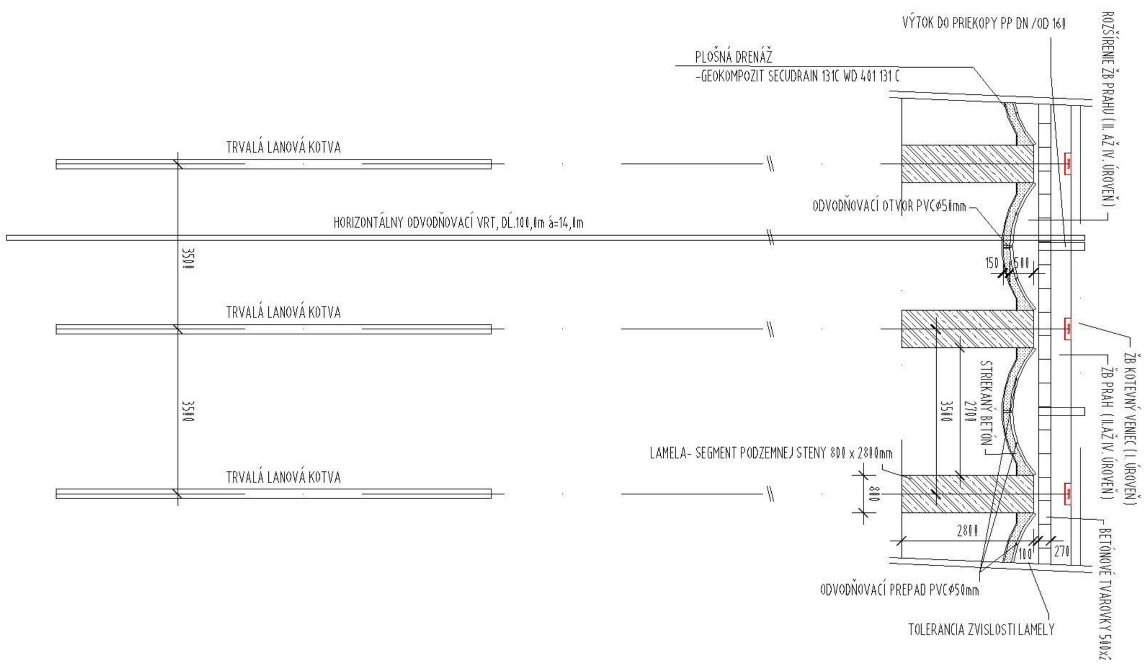

Figure 10. Detail of anchor pass-through in panels and counter-vaults of sprayed concrete and HDW.

(Figure 7) was carried out.

Diaphragm wall panels are in the head part interconnected by a head monolithic beam 1500 mm high and 4500 mm wide. According to terrain configuration, 1–2 beams of dimensions 800 × 800 mm were also used, which additionally stabilize the individual diaphragm wall panels against possible rotation (Figure 8).

However, specifically there is the anchoring of each panel with 1–3 rows of permanent anchors 35.0–54.0 m long, with the number of ropes from 6 to 8 pieces (Figure 9). During the installation, steel beams for the anchors were fixed throughout the monolithic diaphragm wall panels. Furthermore, holes were drilled through the entire length of each panel 2.8 m and then the anchor itself was installed (Figure 10).

Steel reinforcement of each individual panel was optimized with an emphasis on maximum saving of steel while maintaining the necessary rigidity and eliminating bending moments. Between the individual diaphragm wall panel counter-vaults were constructed from sprayed concrete of min. thickness 15 cm and 2 × reinforced with KARI mesh, which are then strongly connected to the panel elements forming a compact element.

In order to drain water from behind the counter-vaults, spatial geo-composite membranes were installed under the sprayed concrete.

To permanently lower the groundwater level in the above the structure, 20 horizontal drainage wells will be constructed between the panels, each 100 m long. The second and the third monolithic beams will serve as a basis for placing the visual cladding of the entire wall made of hollow blocks.

5. Conclusions

The highway cut with a depth of 17 m was located in a landslide area and the depth of the shear surfaces was found only during construction at 25 m. An unusual technical solution was designed and implemented to ensure the stability of the cut. Anchored diaphragm wall panels were used, which are mainly used to secure construction pits during the foundation of structures. These diaphragm wall panels, 25–32 m deep, were turned perpendicular to the slope and set securely in place with anchors 35–54.0 m long. The roots of the anchors extended beyond the assumed shear surface.

Massive measures were proposed due to the fact that the area above the highway and also the access to the tunnel portal were put at risk.

Inclinometric boreholes were built into the selected diaphragm wall panels and dynamometers were installed in the selected anchor heads. In this way, it will be possible to monitor possible deformations of the diaphragm wall panels and the surrounding environment and thus evaluate the effectiveness and safety of this implemented technical solution.

Acknowledgements

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