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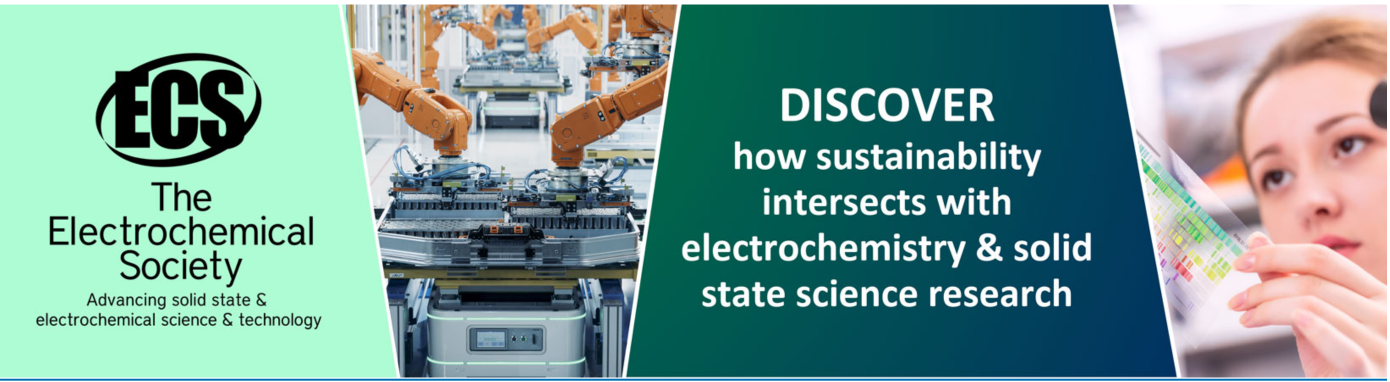

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Ovčiarsko tunnel – interpretation of the results of the geotechnical monitoring

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Abstract. The Ovčiarsko twin-tube tunnel is part of the development of the Hričovské Podhradie – Lietavská Lúčka section of the D1 motorway, running southwest of the Žilina town. The D1 motorway overcomes the detached mass of an overthrust sheet and the western adge of the Paleogene fill of the Žilina Basin through the Ovčiarsko tunnel. The 2T – 8 category is designated for the Ovčiarsko tunnel with the total length of the northern tunnel tube 2360 m and southern tunnel tube 2367 m. the tunnel orientation to the cardinals is on the west-east axis, the marking of tunnel portals and tunnels tubes is distinguished according to it. The design speed is 100 km/h, respectively 90 km/h under worsened weather conditions. Parts of the tunnel are three cross passages passable for vehicles and five cross passages passable for pedestrians, serving as protected escape routes. This report describes geotechnical monitoring, construction technology and procedures with respect to complicated geological conditions. The geological conditions require the operative approach of the project owner, contractor, designer and geologist to the optimum solution for the running of the tunnel construction.

1. Introduction

Slovakia's location is important for all countries in Europe, especially as a transit country through which the lead one of the major pan-European corridors, Corridor V (Venice - Trieste / Koper - Ljubljana - Budapest - Uzhgorod - Lviv). The construction corridor in tunnels Ovčiarsko near the town of Žilina, on the D1 motorway in the section Hričovské Podhradie - Lietavská Lúčka. D1 is the most significant and longest Slovakian motorway, upon completion of which connects Bratislava with Záhor border crossing on the border with Ukraine.

The tunnel orientation to the cardinals is on the west-east axis, the marking of tunnel portals and tunnel tubes is distinguished according to it. The total length of the southern tunnel tube (JTR) on the axis is 2367 m, the mined part is 2320 m long (Figure 1). The route is on two reverse curves with the minimum radius of 739 m. The alignment rises from the western portal on a 1,70 % gradient. The total length of the northern tunnel tube (STR) on the axis is 2360 m, the mined part is 2300 m long. The alignment is again on two reverse curves, with the minimum radius of 777,5 m and rises on a 1,68 % gradient. The tunnel being proposed is of the 2T – 8.0 category with unidirectional traffic. The design speed is 100 km/h, respectively 90 km/h under worsened weather conditions. Parts of the tunnel are three cross passages passable for vehicles with the 3,5x3,6 m cross-sections and five cross passages passable for pedestrians with the 2,0x2,4 m cross-sections, serving as protected escape routes. Construction commencement is 1/2014 and completion 1/2018. Geological documentation and geotechnical monitoring of tunnels excavation provides SG Geotechnika, Inc. and GEOFOS, Ltd.

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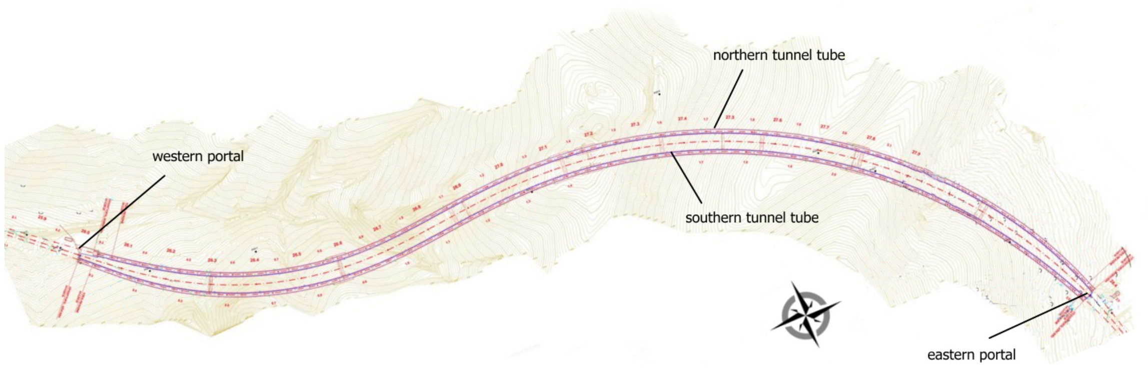


Figure 1. Alignment of the tunnel.

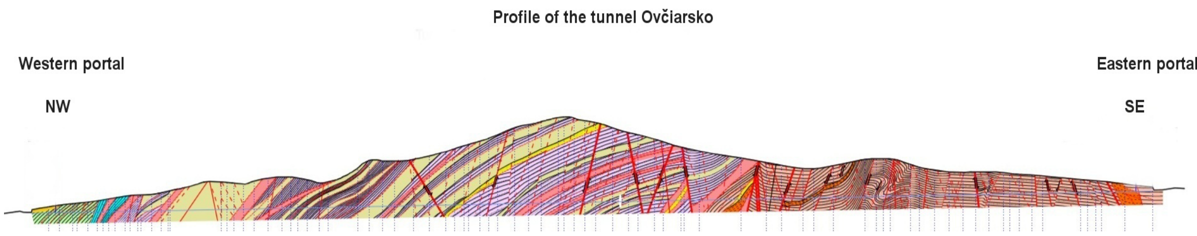
2. Engineering geological conditions

2.1. The geological conditions

The rock mass of the Ovčiarsko tunnel is formed and represented by two basic fault units (Figure 2):

The Manín unit – represented by Mesozoic flysch series of layers formed by series of layers of calcareous clay, marl slate, calcareous claystone, sandstone, and sandy limestone. The rock mass is very tectonically faulted and represents Outer Western Carpathians.

The Inner Carpathian Paleogene, which is represented by flysch series of layers of the Paleogene complex (Inner Western Carpathian). The Paleogene complex is represented by Hričov-Žilina Paleogene (Paleocene), which is represents blocks of limestone and formation of conglomerates, sandstone, and claystone. The younger Paleogene complex (Eocene) is forms by formation of claystone, sandstone, and conglomerate (Súlov and Domanín formation). The youngest complex (young Eocene) is represented by Žilina formation with typical claystone-sandstone rock mass with "colorful claystone" [1]



Legend: Quartery: deluvial caly; Mesozoic: marl and marlite, limestone and sandy limestone; Paleogene: sandy and colorful claystone, formation of conglomerate, sandstone and claystone, Súlov conglomerate, red claystone, sandy claystone; Tectonic: regional faults, sublocal faults, alpine tectonic faults

Figure 2. Geology profile of the Ovčiarsko tunnel [2].

2.2. Hydrogeological conditions

Hydrogeological conditions are subject of the climatic conditions together with geomorphological, drainage conditions, geological and tectonic structure, and other factors (reforestation, etc.). of these factors, it depends on the proportion of infiltrated rainfall. And also, its verified by exploration gallery, which is situated in the location of the northern tunnel tube, thus fulfilling the function of drainage and evacuating water in a gravity way toward the western portal, where it is continually pumped out. In the remaining section of the tunnel hydrogeological conditions were verified by drilling work, which determined groundwater levels. During the excavation from the western portal were larger inflows of groundwater linked to tectonic interfaces and transitions lithological units (usually claystone and conglomerates), but there are no significant groundwater flows into the tunnel driven from the western portal. However, there are significant groundwater flows into the tunnel driven from the eastern portal. The Paleogene complex (Žilina formation) make hydrogeological massif even more significant with the continuous hydrogeological collector layer type with circulation of groundwater mainly in zones of fracture and faulting. The existing drainage system was supplemented by additional horizontal drainage holes bored to the massif south of the southern tunnel tube in the water-bearing zones.

3. Tunnel design

Excavation of tunnel takes place on the bases of the principles of the New Austrian Tunnel Method (NATM), this is a cyclical way of excavation. The so-called "horizontal" excavation sequence design consists of the top heading, bench, and invert. The tunnel is driven from both portals; uphill from the western portal and downhill from the eastern portal. The excavation support consisting of two lining layers – the primary lining from shotcrete and the secondary lining from reinforced concrete. The intermediate waterproofing layer between the two liners is formed by geotextile and a plastic waterproofing membrane. The excavation operations are organised depending on the type of the rock mass, either by mechanical excavation (tunnel excavator) or using the drill and blast.

3.1. Primary tunnel lining

There are 16 excavation support classes which proposed for the excavation of the road tunnel. In comparison to the tender documents, excavation support classes VT4/2 was added for the excavation in the best geotechnical conditions (conglomerates and sandstone, figures 3). Excavation support classes (table 1) VT 7MP, VT 7/1, VT8/1, and VT8/1MP were proposed for the portal area of the portal and VT 6/5, VT 6/4, VT 6/2, VT 6/1, and VT 7/2 for the bad geotechnical conditions and for the fault zones, and VT 5/2 NZ and VT 6/2 NZ for the emergency bay. The following elements are used for restoring the ground mass stability disturbed by the excavation [3]:

- shotcrete – C 25/30 grade, with the strength gain on the J2 curve
- lattice girder is designed for the top heading and bench primary lining
- steel mesh with 6x6 /150x150, 8x8/150x150, 8x8/100x100 mm and steel grade B 500 B
- hydraulically expanded rockbolts 3 m and 4 m long – 150 kN
- grouted rockbolts anchors – Ø28 mm, the length of 3, 4 and 6 m – 250 kN, B500B
- self-drilling rockbolts R32; 4,6 and 8 m long– 280 kN
- self-drilling spiles 4 m long – R32, 9 m long – R51 and 4 m and 9 m long
- canopy tube pre-support from grouted steel tubes Ø 114/6.3, 18 m long
- cement grout – strength of 25 MPa, cement R32.5 or AM25

Figure 3. Excavation of the southern tunnel tube with excavation support class VT4/2 - massive conglomerates without tectonic deformation (Súlov formation).

Table 1. Geological conditions with excavation support class.

Excavation support class	Value of RMR/quality of the rock mass	Geological conditions
8MP	0-20/very poor	Formation of the heavy weathering claystone (eastern portal)
7MP	0-20/very poor	Formation of the heavy weathering siltstone, claystone, and sandstone (western portal)
7/2	0-20/very poor	Weakly to moderate weathering siltstone and claystone
6/5	24-30/poor	Calcareous claystone with sandy limestone, moderate to heavy weathering
6/4	28-35/poor	Sandy limestone, claystone, and siltstone, weakly to moderate weathering
6/2	33-40/poor	Formation of claystone, siltstone, and sandstone (calcareous sandstone – sandy limestone), weakly to moderate weathering
5/2	Min. 45/fair	Conglomerates, sandstones, siltstones, claystone (flysch series), healthy to weakly weathering
4/2	≥50/fair	Massive conglomerates with sandstone and claystone, healthy to weakly weathering

3.2. Secondary tunnel lining

The secondary tunnel lining is designed as a 0.3 m thick reinforced concrete structure from C30/37-XF4, XC3 concrete (up to the distance of 150 m from portals) and C25/30-XF2, XC3 concrete (in the internal tunnel section). Concrete is to be cast behind a movable formwork. The length of the expansion blocks is 12.5 m. The lining is reinforced with steel mesh, bar reinforcement and auxiliary lattice girders used for the realisation of the reinforcement of individual blocks of the secondary lining. B500B steel is used for all reinforcement of the secondary lining. The installation of the secondary lining is possible only after the primary lining deformations stabilise.

3.3. Tunnel waterproofing

The tunnel tube lining system is designed as a sandwich structure consisting of a primary lining and secondary lining. A drainage and waterproofing layer consisting of min. 900 g/m^2 geotextile and min.

2 mm thick waterproofing membrane is inserted between the two liners. The umbrella-type waterproofing system is designed for the tunnel. The invert is not provided with waterproofing. The drainage layer of the waterproofing evacuates groundwater to the DN 200 mm side drainage system. Drainage water is directed from cleaning niches to a collector sewer located under the left-hand traffic lane.

4. Geotechnical monitoring

Principles of the NATM consist in controlling of the deformation process surrounding the excavation, which include geotechnical documentation of the rock mass, lining deformations and extensometer measurement, measurement of stress in primary lining and contact primary lining-ground, measurement of water outflow from the exploratory gallery, physical-chemical analyses of water, supervision of warning states (value "A") and hydromonitoring (measurement of groundwater level). And, there is monitoring in the area of the portals. The following measurement activities are performed in the area. 3D measurement of deformations, measurement of stress in anchors, automatic surveying system on the eastern portal face, inclinometer measurements and inclinometer deformation measurements.

There are 20 (STR) and 14 (JTR) geotechnical block that are characteristic with the following principles. On the bases of the RMR classification [4], excavation support class and geological with tectonic situation of the rock mass and geotechnical situation.

We can divide the geotechnical blocks to the three elementary parts on the bases of the rock mass age and tectonic deformation (section with significant and local deformation and section without deformation). The first section is a mass of Mesozoic rock (claystone, limestone, and sandstone) with very tectonic deformation and steep layers. General course of the layers is NE-SW (orientation of plunge is to NW with 45-60 °) and tectonic is NE-SW and SE-NW (with orientation to NW and NE with 60-80 °). The next section is Paleogene complex of claystone, sandstone, and conglomerates. There is section with or without tectonic deformation and the best of geotechnical block (excavation support class 4/2) for the conglomerates (Súlov rock formation) with the length of the block 147.3 m. The general course of the layers and faults is almost same as previous section. Formation of folding claystone and sandstone (there are a minimum of sandstone, figures 4) represents Paleogene complex of Žilina formation. The orientation of the layers is NE-SW (with orientation to NW and 10-30 °) and faults with NW-SE trend (SW and NE plunge with 60-80 °).

Figure 4. Paleogene complex (Žilina formation) of subhorizontal claystone, siltstone, and sandstone layers.

The value of the supervision of warning states are high level of safety, allowable state changes and critical condition (Critical state was achieved exceeding 125 % of the limit value "A".)

Extensometer measurements are used to analyse the behaviour of the rock mass around the excavation interact with the primary lining. Extensometer is measured relative deformation between the anchor point and head extensometer. Extensometer are designed with a rod of glass fibber guided in a protective tube, especially for reading mechanical and hydraulic anchor point. In each main measurement profile of the excavation is build threesome radially arranged three-stage extensometers with Tread depth 3.6 and 9 m.

Measurement of stress on the primary lining-ground contact using pressure measurement boxes. The purpose is to determine the load bearing capacity of the primary lining deforming rock mass. In each main profile measurement needs to be installed five pressure measurement boxes distributed around the perimeter of the excavation. The principle of measure of stress in the primary lining using the same method as previously measurement.

Tension in the secondary lining is measured indirectly by detecting the vibration of strain using tensiometer mounted on the rod of concrete reinforcement at the outer and inner surfaces. Vibration tensiometer consist of two parts a steel wire stretched between two retaining blocks and measuring the drive coil. Deformation of the structure will produce mutual shift the retained strain gauge blocks, changing the length respectively. tension steel wire, which is measured as the natural frequency of oscillation of the excitation. Part of each tensiometer is a thermometer. Vibration tensiometer is installed in the main measurement profile (10 respectively 12 vibration Sensors).

Lining deformation measurement is carried out in three dimensions by routine geodetic surveying using total stations. Optical reflector targets are installed at sections along the tunnel (every 10 to 20 meters). There are typically 5 reflectors, which are installed in each section: upper vault (crown), mid vault, and at the wall sides.

Table 2. Limits of the lining deformation measurement.

Excavation support class	Top heading deformation (mm)
8MP	130
7MP	130
7/2	120
6/5	80
6/4	60
6/2	35
6/1	30
5/2	20
4/2	20

5. Conclusion and discussion

The tunnel excavation was completed in August 2016 and now work is continuing the secondary lining. Geotechnical monitoring of Ovčiarsko tunnel was continuously carried out under the approved project geotechnical monitoring. The basic objective of the monitoring was to compare the identified engineering geological and geotechnical conditions with the assumptions of standard project.

Based on continuous geological documentation of the individual advance, the engineering geological and geotechnical characteristics of the massif were evaluated for the determination of the excavation support class. The most important criterion for determining the equipment class was the point assessment of the rock mass according to the classification system RMR and QTS, which are based on parameters such as strength of intact rock material, drill core quality (RQD index), spacing and condition of discontinuities, ground water, etc.

The observed geotechnical conditions in the tunnel were almost the same as the predicted geological conditions in the presupposition. The main differences were in percentage of the support classes, percentage of the clay, sandstones and conglomerates and groundwater flows into the tunnel. During the excavation of the tunnel, generally better excavation support class were defined than assumed. The excavation was mostly done in the support class 4/2 (almost 45 %) with massive conglomerates and sandstones.

The most unfavourable excavation conditions were in portal areas (highly weathered and decomposed rock mass) and chainage 432.83 to 527.38 tunnel meter of the northern tunnel tube (significant representation of tectonically damaged rocks and very favourable discontinuity orientation). The tectonic zones were mostly bound to the intersection of the sandstone (conglomerates) and claystones with tributaries of groundwater into the tunnel tube (water inflows to 0.1 l/s).

The overall hydrogeological assessment of portals and tunnel routes was favourable. There was no correlation or influence of the underground water of the basal conglomerates on a spatially extensive hydrogeological structure with a great water-management significance between near villages. The inflows of groundwater complicated the excavation through a change in the geological characteristics (tectonic zones and lithostratigraphic layer). The most unfavourable hydrogeological conditions were in the eastern portal. In the sedimentary sediments, accumulated water, which negatively influences the geotechnical properties of the rocks. Artificial drainage improved the situation.

The maximum of top heading deformation in the western portal were 4.1-35.9 mm (STR, VT 4/2-5/2), 6.0-29.7 mm (JTR, VT 4/2-5/2) and 9.6-94.7 mm (STR VT 6/2), 17.1-104.5 mm (JTR, VT 7MP-8/1) in the eastern portal. And maximum of lining deformation was 5.1-46.8 mm (STR), 3.8-26.0 mm (JTR) in the wester portal and 2.9-32.4 mm (STR), 10.8-87.4 mm (JTR) in the eastern area. Now all deformations are in the state of permissible changes.

As the results of the geotechnical monitoring show, the excavation in the southern tunnel tube from the eastern portal was very complicated (weather and tectonic condition, very unfavourable of discontinuity orientation and presence of groundwater). Whole area of the eastern area represented very unfavourable geotechnical conditions.

Laboratory testing of the properties of the rock material has shown its extreme heterogeneity and the resulting complications in its construction use. The highest quality material (conglomerates, which consist predominantly of dolomite with a small proportion of other minerals). Use them for more demanding construction purposes (concrete or underlying road surface) is limited by the low frost resistance of this material. Flysch rocks are hampered by the frequent and irregular layers of conglomerates, sandstones and claystones. It is possible to characterize the materials as suitable for use in the lower and central portions of the backfill, respectively as a lesser quality part of the sandwich type.

Despite the bad geotechnical conditions during the excavation, the tunnel will be opened in the assumed term in the first quarter of 2018, the Ovčiarsko tunnel will become part of the traffic junction on the D1 motorway and will significantly contribute to the improvement of the traffic situation in Žilina region.

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