

VIŠŇOVÉ TUNEL – FROM THE FOUNDATION STONE TO THE FIRST PASSAGE

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ABSTRACT: The paper presents a retrospective analysis of the evolution of geotechnical knowledge and risk management during preparation and construction of the Višňové motorway tunnel, the longest road tunnel in Slovakia. The work chronologically maps the transformation of the engineering geological model (EG model) of the Lúčanská Malá Fatra rock mass, reflecting key findings obtained from the exploration adit, long-term monitoring, and the actual implementation of the main tunnel tubes. Special attention is given to the identification of critical geotechnical factors, such as extreme hydrostatic pressures (up to 3.1 MPa), tectonically crushed mylonite zones, and time-dependent phenomena – notably environmental sulfate aggressiveness and the kinetics of incrustation formation in drainage systems. The contribution analyzes in detail fundamental design adaptations triggered by verified data and changes in European legislation, including the modification of the ventilation system and the conversion of the exploration adit into a main drainage collector.

1. INTRODUCTION

In terms of scale, geological conditions, and technical complexity, the Višňové motorway tunnel represents one of the most challenging engineering tasks in the Central European region. The implementation of this project is not merely the result of a standard project cycle but represents the culmination of iterative learning about the anisotropic and tectonically heavily disturbed rock mass of Lúčanská Malá Fatra. Each stage of the project – from initial studies to the final implementation of technological equipment – was determined by a progressive increase in geotechnical knowledge and the necessity to adapt technical solutions to actual in situ conditions.

Tunel Višňové



Figure 1: Location of the Višňové tunnel on the map of Slovakia

The main objective of this paper is a chronological analysis of the evolution of the rock mass geotechnical model and an impact assessment of these findings on the preparation of project documentation. The

paper focuses on the identification of key geotechnical risks in the individual phases of preparation and construction, while analyzing how the validation of data from the exploration adit and subsequent long-term monitoring influenced the choice of tunneling methods, lining design, and the drainage system. The document tracks the methodological shift from initial geotechnical uncertainties and hypotheses, based on indirect investigation methods, to verified data obtained during excavation and subsequent diagnostics of the structure.

The analysis is structured into logical sections: from the initial engineering geological (EG) model, through key hydrogeological and tectonic findings from the exploration adit, to the identification of time-dependent degradation processes (sulfate aggressiveness, incrustation). In the final part, the paper reflects on the risks associated with workmanship quality and quality management during the final phase of construction. The presented synthesis thus serves as a professional case study, defining new reference standards for the investigation, design, and implementation of underground works in the complex geological conditions of the Western Carpathians.

2. PHASE I: INITIAL HYPOTHESES AND RECONNAISSANCE SURVEY (1997 – 1998)

The reconnaissance phase of the engineering geological investigation (EGI) represented the primary step in the process of defining the geotechnical uncertainties of the rock mass. Its main goal was not a detailed quantification of parameters, but the identification of critical areas and determining the scope of the necessary detailed investigation for a project of national significance.

The baseline engineering geological model, derived from surface mapping, archival data, and a limited set of core boreholes, defined the rock mass as a heterogeneous entity consisting of a crystalline core with predicted tectonic lines at the contact with Mesozoic rocks. Although this model indicated a high degree of geotechnical difficulty, the precise spatial distribution and mechanical properties of discontinuities remained unverified due to the high overburden (exceeding 500 m in some places).

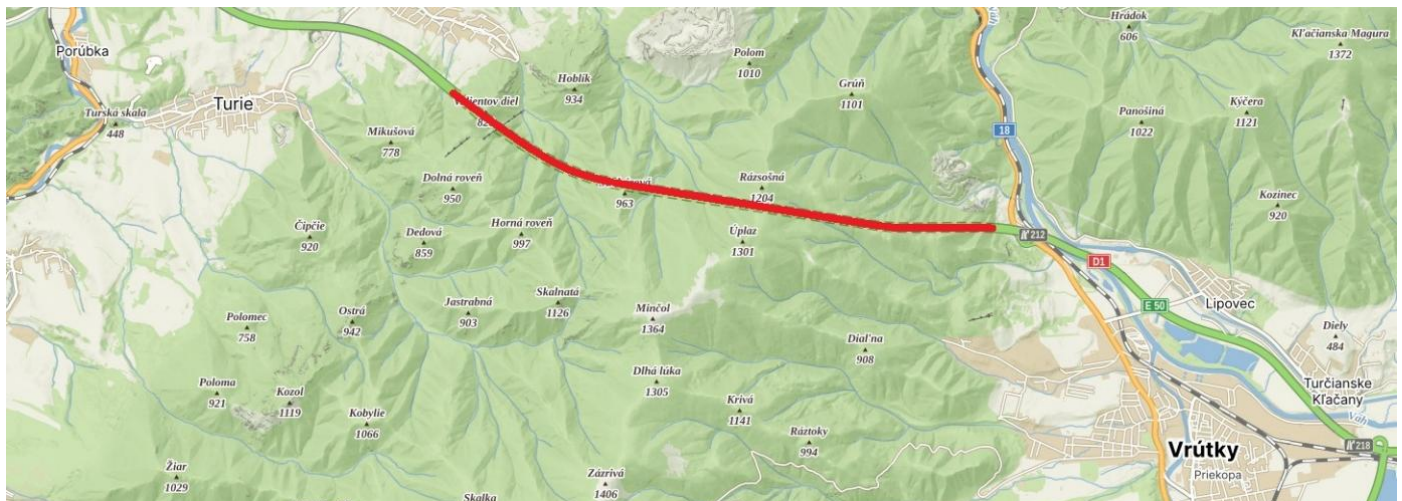


Figure 2: Location of the Višňové tunnel between Žilina and Martin (source: mapy.com)

Key geotechnical risks were classified in this phase in the following areas:

- Assumption of intensive disturbance of the granitoid rock mass with the occurrence of fault systems. However, exact data on the orientation, thickness, and filling of fault zones, as well as the kinematics of the faults, were absent.
- Risk was concentrated primarily on the tectonic contact between the crystalline core and the Mesozoic, where the presence of weakened zones with reduced excavation stability was anticipated.
- Forecasts indicated the presence of significant groundwater accumulations tied to fissure-fault permeability. However, quantitative data on hydrodynamic parameters and the potential impact of tunneling on the groundwater regime were missing.

A fundamental output of the reconnaissance survey was the finding that indirect methods and surface borehole investigation were insufficient under the given morphological and geological conditions for a safe and economical tunnel design. Based on these conclusions, an exploration adit was proposed along the tunnel alignment.

In the context of that time (mid-1990s), a single-tube tunnel concept with two-way traffic was designed, where the exploration adit was intended to serve as a parallel escape route after the completion of excavation.

3. PHASE II: FINDINGS FROM THE EXPLORATION ADIT (1998 – 2002)

The driving of the exploration adit between 1998 and 2002 represented a key stage in understanding the rock mass.

This step enabled the transition from theoretical assumptions and interpretations of surface exploration to direct in situ verification of the rock environment. The exact data obtained revealed an extreme degree of geotechnical complexity, which in many aspects exceeded the original forecasts.

The exploration adit fundamentally changed the engineering geological model and transformed the identified risks into measurable technical parameters:

In the granitoid core, extensive cataclastic and mylonite zones were documented – belts of intensely crushed and hydrothermally altered rock. The thickness of these zones locally reached up to 12 meters. In these sections, the rock mass exhibited properties of a highly anisotropic environment with low shear strength.

The adit intersected a key discontinuity – the Kunerad fault. This zone was identified as a critical geotechnical risk, where the rock was transformed into tectonic debris which, upon contact with water, acquired the character of non-cohesive soil.

Sections with unfavorable mechanical-physical properties were directly documented, particularly Gutenstein limestones (Vgn, Vgtp) with manifestations of karstification, and zones of carbonate claystones and cataclasites (Iktp).

The most significant findings from the adit were in the field of hydrogeology. The combination of extreme water pressure and tectonically crushed material created perfect conditions for suffosion.

Table 1: Selection of prominent hydrogeological parameters

<i>Hydrogeological Parameter</i>	<i>Observed Value (1998-2002)</i>	<i>Engineering and Risk Impact</i>
<i>Maximum outflow from the eastern portal</i>	<i>> 420 l/s</i>	<i>Indicator of sudden water inflow risk; parameter for dimensioning emergency drainage and pumping capacities when driving at a downward gradient (Matejček and Bohyník, 2006).</i>
<i>Maximum face inflows</i>	<i>80 – 160 l/s</i>	<i>Immediate threat to excavation stability, risk of flooding equipment and personnel, need for massive pumping capacities (Ondrášik et al., 2015).</i>
<i>Hydrostatic water pressure</i>	<i>Up to 3,1 MPa</i>	<i>Extreme load on the lining; suffosion effect that washed out tectonic debris, created caverns, and led to cave-ins (Ondrášik et al., 2015).</i>
<i>Stabilized outflow from the rock mass</i>	<i>230 – 260 l/s</i>	<i>Confirmation that the tunnel acts as a permanent linear drain, which changes the hydrogeological regime and lowers the groundwater level in the region (Bohyník et al., 2018).</i>

Sudden water inflows, loss of stability in mylonite zones, and extreme water pressure became the dominant factors that had to be considered in every subsequent design step.

Table 2: Selected risks identified by long-term observation

<i>Identified Risk</i>	<i>Description and Technical Impact</i>
<i>Sulfate aggressiveness</i>	<i>In the chainage section 1 250 – 1 800 m (Mesozoic), the presence of gypsum and anhydrite was confirmed, the leaching of which caused visible degradation of the primary lining shotcrete. A similar risk (degree XA2) was also identified in the section 300 – 800 m from the western portal. These findings led to a requirement for the use of sulfate-resistant concrete for the final lining (Geofos, 2007).</i>
<i>Incrustation / Sintering</i>	<i>Long-term monitoring in the escape adit confirmed massive precipitation of calcium carbonate, which clogged drainage channels and reduced drainage efficiency. Analyses showed that calcium carbonate leached primarily from concrete structures and setting accelerators, not from the rock. This risk necessitated a drainage system design allowing for regular maintenance and, in some cases, its complete reconstruction (Geofos, 2007).</i>
<i>Reactivation of slope deformations</i>	<i>Systematic monitoring (boreholes HG-1, HG-2) confirmed the reactivation of slope deformations above the western portal access road, which occurred on April 4, 2006, after extreme warming and precipitation. These data confirmed the high sensitivity of portal stability to the hydrogeological regime and the necessity of permanent geotechnical monitoring and robust stabilization measures (Matejček, 2011).</i>

The significance of these findings lay in the confirmation that the tunnel's life cycle must be considered not only from the perspective of immediate stability during construction but also in terms of long-term material durability and the functionality of operational systems.

6. PHASE V: IMPLEMENTATION AND NEW RISKS (2014 – 2025)

The main construction phase brought a fundamental shift in risk perception. After decades of detailed investigation, the focus changed. It was no longer about managing geological uncertainty, but about managing known, albeit extreme, geological conditions. The dominant risk thus shifted from the area of managing the natural system to the field of quality assurance, workmanship quality, and management in a challenging environment.

6.1 ADAPTATION OF THE ADECO-RS EXCAVATION METHOD

Because of conditions along the tunnel alignment, particularly in zones of tectonically crushed and water-bearing mylonites, the ADECO-RS excavation method (Analysis of Controlled Deformation in Rocks and Soils) was adopted. Unlike the traditional NATM (NRTM), which focuses on managing deformations behind the excavation face, the key principle of ADECO-RS is active stabilization of the rock mass in advance of the face.

6.2 CONVERSION OF THE EXPLORATION ADIT INTO A MAIN DRAINAGE COLLECTOR

One of the most significant decisions during the tunnel's completion was a complete change in the function of the original exploration adit, which is ultimately utilized as a main drainage collector for groundwater.

By utilizing the existing adit, the need to build extensive sewer collectors directly under the roadway in both tunnel tubes was eliminated. This approach prevents future pavement failures at the locations of inspection shafts, which are a common cause of defects in other tunnels. Rock water from the back-drainage is safely directed into the adit, which carries it away from the traffic space.

The drainage adit has a total length of 7 446,75 meters and consists of four sections: the eastern and western portal sections of the adit had to be rebuilt due to changes in the portal alignment, while the original sections of the adit were driven using NATM (NRTM) methods and a tunnel boring machine (TBM).

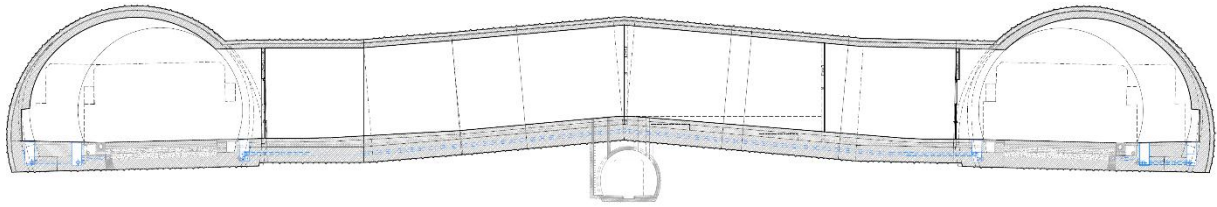


Figure 4. – Longitudinal section of cross connection No. 1, drainage tunnel is directly below the cross connection

6.3 OPTIMIZATION OF TECHNICAL SOLUTIONS IN THE FINAL STAGE OF CONSTRUCTION

In the final phase of construction, the evolution of technical standards and increasing demands for operational safety necessitated a comprehensive optimization of the project documentation. To ensure the seamless progression of works, a precise inventory (passportization) and diagnostics of the already implemented sections of the secondary lining were conducted, verifying their structural integrity and compliance with the design parameters.

Subsequently, the design team developed a comprehensive set of technical adjustments aimed at maximizing the utilization of the previously executed structures and integrating them into a fully functional and safe system. These design adaptations focused primarily on systematically enhancing the long-term sustainability of the tunnel.

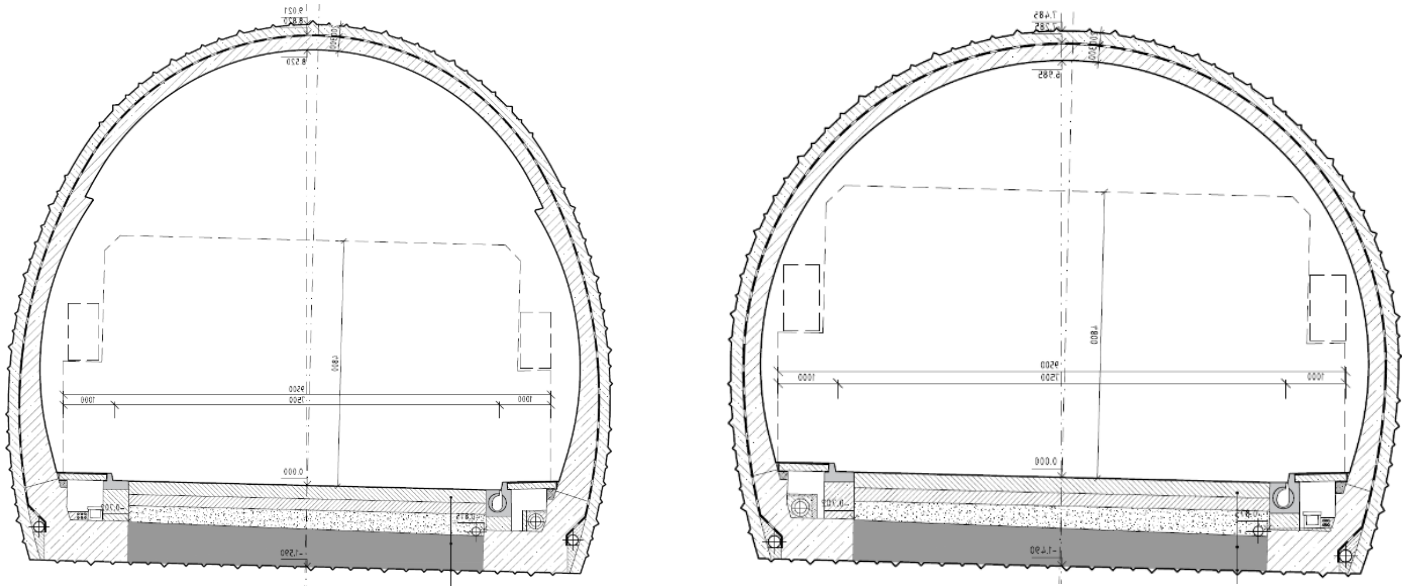


Figure 5: Typical cross-section of a tunnel, left with preparation for intermediate ceiling, right without intermediate ceiling

6.3.1 Change of ventilation concept and finalization of the tunnel tube profile

A strategic decision that influenced several aspects of the project was the definitive change of the ventilation system from the originally planned semi-transverse ventilation to a final solution featuring longitudinal ventilation. This approach is implemented using jet fans positioned in the tunnel crown.

A direct consequence of this change was the elimination of the need to build an intermediate ceiling along the entire length of the tunnel, which was originally intended to serve as a separate ventilation duct. Despite the fact that the intermediate ceiling was not implemented, the physical preparation for its installation (reinforced nips in the lining) remained preserved in a section of the tunnel (from block J399 in the south tube and S400 in the north tube), representing a permanent structural characteristic inherited from the original project. Ultimately, the intermediate ceiling was constructed only at a specific location – in emergency bay No. 3 in both tunnel tubes – for the purpose of connecting ventilation ducts leading from the already existing ventilation shaft.

6.3.2 New functional use of the ventilation shaft

The ventilation shaft, which was nearly finished at the time of construction take-over, lost its original function as a result of the change in the ventilation concept. Instead of its demolition, a decision was made to adapt it for new purposes.

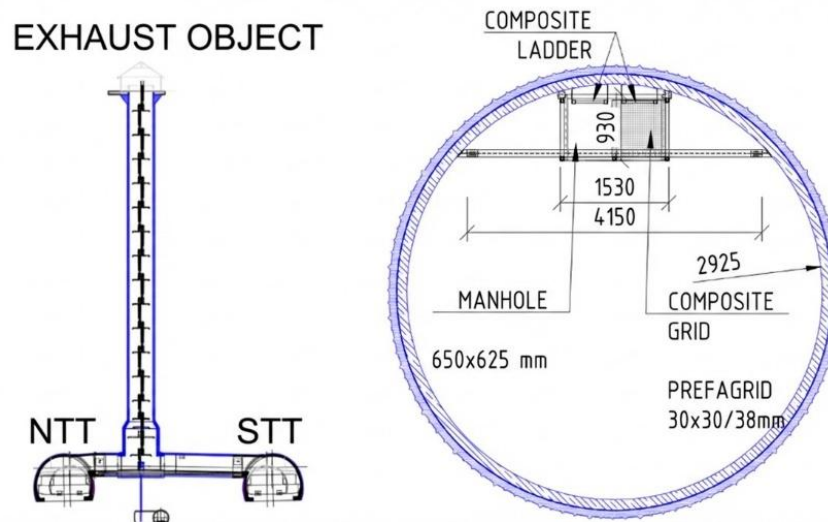


Figure 6: Left: cross-section of the tunnel and ventilation shaft; right: floor plan of the ventilation shaft

Currently, the shaft serves exclusively for inspection and service purposes. For this purpose, a new ladder section was built within it, allowing safe access throughout its entire height. The structure consists of 16 inspection platforms, which are interconnected by ladders. With the aim of maximizing durability and minimizing maintenance costs in the challenging and damp environment of the shaft, modern composite materials were used for the construction of the platforms and ladders. In the given environment, these materials do not have limi

ting factors in terms of lifespan as is the case with traditional steel structures, where it is necessary to address corrosion resistance.

7. CONCLUSION AND EXPERIENCES FROM THE VIŠŇOVÉ TUNNEL PROJECT

The chronological journey of exploring the Višňové rock mass represents a compelling example of the evolution of risk management in modern tunneling. The project moved from general geological uncertainty, through the identification of specific and measurable hydrogeological threats, to the subsequent revelation of time-dependent material degradation processes and fundamental adjustments during the construction process.

Three key experiences emerge from this complex case study, possessing timeless relevance for any future large-scale underground project:

The project unequivocally confirmed that in complex geological conditions, surface investigation methods could be insufficient. Without direct data from the exploration adit, the implementation of the main tunnel tubes could have been highly risky.

Geotechnical risk is not a static parameter defined at the project's outset. The Višňové project demonstrated that risk, or rather the understanding of it, evolves over time. The importance of long-term monitoring was proven in the discovery of time-dependent phenomena, such as sulfate aggressiveness toward concrete and the incrustation (clogging) of drainage systems, which are crucial for the long-term durability and operability of the structure.

The most important conclusion is that in a complex underground structure, the quality and precision of construction implementation (workmanship quality) is just as critical a factor as managing the geological conditions themselves. A failure in quality control can completely negate all knowledge and safety gained through demanding and costly exploration.

The Višňové tunnel thus remains not only a key transport structure for Slovakia but, above all, a reference case study for future generations of geotechnical engineers and tunnelers. Its legacy is that the deepest knowledge of the rock is worthless without an equally deep responsibility during its transformation.

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