The Challenges of the first NATM Highway tunnel of Romania

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ABSTRACT: Romania’s first motorway tunnel was built using the New Austrian Tunnelling Method (NATM) - the 1,350 m long Momaia Tunnel on the A1 motorway between Sibiu and Pitesti. The project forms part of the TEN-T corridor and was delivered under a design-and-build contract. The twin-tube tunnel was excavated in highly variable sediments of the Dacian Basin. Actual ground conditions, consisting of heterogeneous clay, silt, and sand layers with low cohesion and local landslide features, differed significantly from the initial geological forecasts and resulted in demanding excavation conditions. These challenges were successfully managed through adaptive excavation and support strategies tailored to the observed ground behavior. Despite elevated geological risks, the tunnel was completed safely and on schedule, demonstrating that NATM can be effectively applied under complex soft-ground conditions when combined with strong technical expertise and proactive risk management.

1. INTRODUCTION

1.1 PROJECT PRESENTATION & PROJECT PARTICIPANTS

The new A1 motorway between the Romanian cities of Sibiu and Pitest is a core section of the Trans-European Transport Network (TEN-T) and, once completed, will form an important part of the continuous high-speed route for intra-European freight and passenger transport from the North- and Baltic Sea to the shores of the Black Sea.

With the signing of the contract on 15th November 2021, PORR was commissioned in a design & build contract to construct the almost 10 km long Lot 4 section of the new A1 highway. The centrepiece of that project is the 1350 m long Momaia Tunnel. It is the first NATM tunnel in Romania on the national road network.

The design of the twin tunnels was undertaken by the engineering group iC consulenten, a long-standing partner of PORR. Both companies are well situated in the central European underground business and market leaders in various fields of engineering.

The client is the Romanian road authority CNAIR, technically represented by the engineering consultants TPF Inginerie, with the responsibility particular for construction supervision.

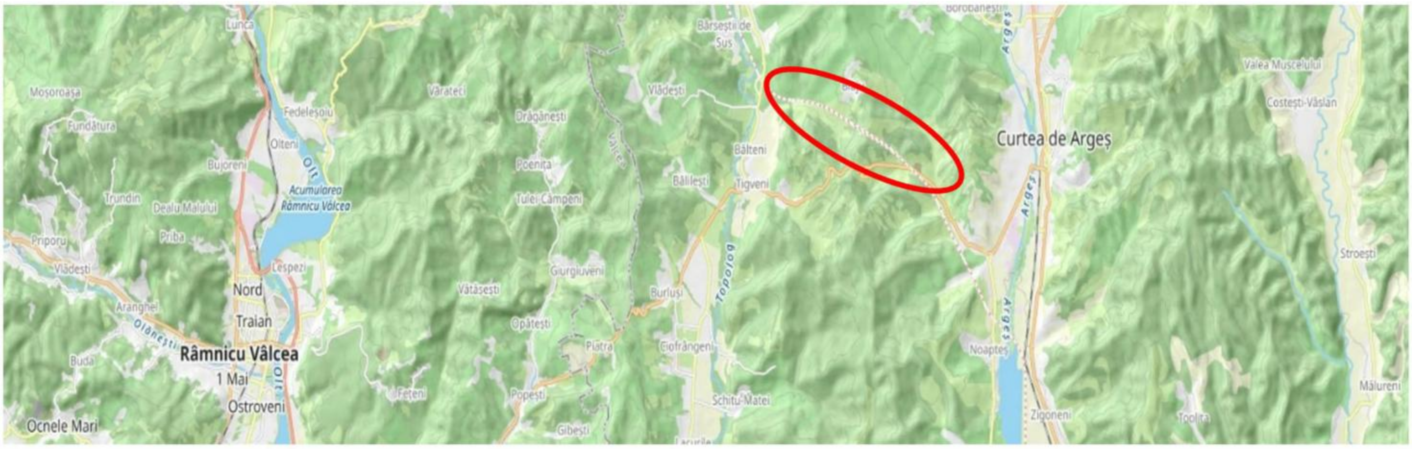
1.2 LOCATION & GEOLOGY

The tunnel is located in central Romania, on the border between Wallachia and Transylvania, near the culturally significant city of Curtea de Argeș [Figure 1], which is particularly well known for its cathedral and the Transfăgărășan mountain road, that starts there. The area around that majestic mountain road and the Vidraru Lake is one of the touristic magnets of Romania and as well a hot spot of the biggest brown bear population in the European Union. Until now, the city was only connected to the nearest major centre in Sibiu and Pitesti by country roads.

Geologically, the tunnel runs through sediments on the northern edge of the Central Dacian Basin at the transition to the Southern Carpathians and represents a peripheral area of the Paratethys, which began to recede there in the Pliocene. In the area of the tunnel, there is the transition of the Pontian sediments (sands-partially cemented to sandstone, cohesive clays and silts) to the concordant Dacian sediments (clays, clayey-silty sands, sandy marls and gravel layers) above (Jipa et al., 2013; Jorisson et al., 2018). These layers have been mapped in the tunnel area, which dip slightly at approx. 10-15° south-southwest against the direction of the tunnel drive. No fault zones were expected, the minimum overburden of the tunnel was approximately 3 m, the maximum cover approximately 100 m.

During the advance, almost exclusively highly variable layers of clay and silt interspersed with sandy layers were encountered. The clayey/silty layers were frequently interspersed with irregular oriented slickensides, each measuring several cm^2 to dm^2. This led to an effective lack of cohesion in the clayey/silty layers. The sand layers were encountered in thicknesses ranging from a few centimetres to several metres, with a highly variable fine grain content and corresponding instability.

During the campaign of geological research some landslides had been encountered and mapped. That ground movements needed additional measures to assure a safe tunnel excavation and a high quality and durability of the structures itself.



2. TUNNELDESIGN

The tunnel is a twin-tube tunnel with an excavation area of 135 m^2 each [Figure 2], connected by three cross passages (one of which is passable by emergency and maintenance vehicles) and an axle distance between the tubes of approx. 35 m. There will be two motor lanes available in each direction. The outer shell was constructed from two layers of reinforced shotcrete with 25 – 45 cm thickness. In the portal areas with low cover, a pipe roof umbrella section (d=114 mm, L=15 m; 5 and 7 sections at each portal side) were installed, while in the rest of the tunnel, full spiles with d=30 mm and L=4 m were used. Self-drilling injection bolts (R32-250 kN) in lengths of mainly between 6 and 15 m were applied to anchor the system, depending on the prevailing geological conditions [Figure 4]. The tunnel tubes are drained and protected against mountain water ingress by an umbrella sealing. The shell thickness of the inner lining is 40 cm at the ridge and 80 cm at the transition to the abutment, with a standard block length of 12.5 m. As there are no normative regulations specifically for tunnel construction in Romania yet, Eurocodes and Austrian tunnelling guidelines were used for the planning and execution of the tunnel.

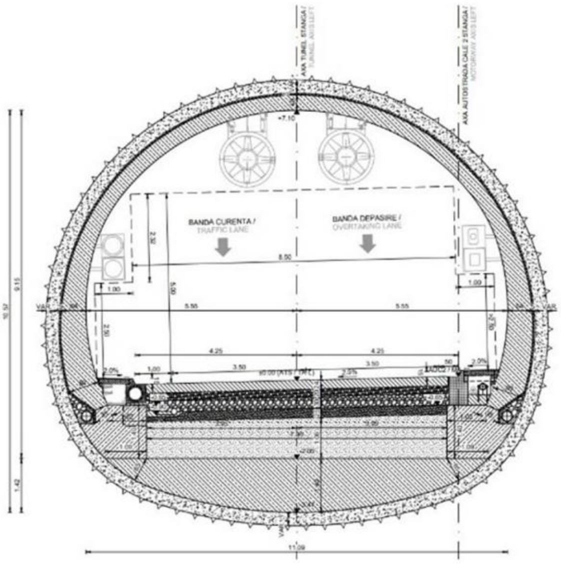


Figure 2: Regular cross section Type 1

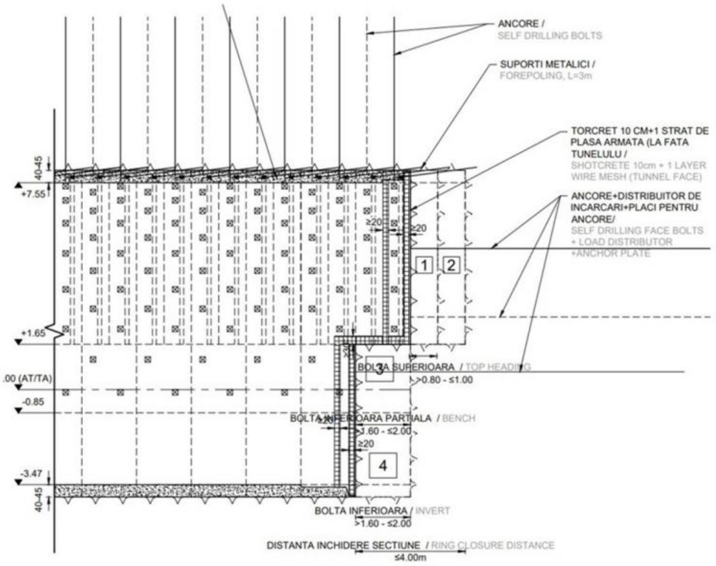


Figure 3: Excavation and support Type 5

As mentioned during the geological mapping campaign landslides in the project are had been encountered. To evaluate the impact to the tunnel structures additional investigations had been undertaken. First all available satellite and georeferenced pictures had been collected and evaluated. That pictures show an annual surface movement of up to 15 Milimeters in the project area.

Based on the findings an additional drilling campaign had been executed and inclinometers and piezometers had been installed. In the drillings itself borehole tests had been made and the cores undergo laboratory testing at the University of Graz/Austria.

The result of that research campaign was that only surface slides in depths up to 30 meters are encountered. As well it was found out that the mass movements are nearly parallel along the tunnel axis. For that reason box shaped portals had been designed that are founded with heavy reinforeced piles. That piles act like an anchor in the stabile – not moving – stratigraphic layers.

Figure 4: Portal Situation with site installations

Additionally measures had been undertaken that the blocks of the secondary lining can move freely without damaging the water proofing membrane and concrete structure itself.

3. PROCEDURE & CHALLENGES DURING TUNNEL DRIVE

3.1 EXCAVATION CONCEPT

The Momaia Tunnel is Romania's first mined motorway tunnel and the first tunnel in Romania to be constructed using the New Austrian Tunnelling Method (NATM).

The concept planned a rapid ring closure [Figure 3] with a short trailing invert for the excavation works. For the advance a Liebherr L950 tunnel excavator with a ripper [Figure 5], bucket [Figure 6], optional road header and hydraulic chisel was used. Shotcrete application was executed with a Putzmeister Wetcret 5 shotcrete manipulator and a two-arm Sandvik DT922i drilling rig was used for all drilling works like fore poling and anchoring. The concrete was supplied by a construction site concrete mixing plant located near the portal. For the spraying and securing works a shotcrete C30/37 J2 with an alkali-free accelerator was applied. Both tunnel tubes were excavated in parallel in a 24/7 shift operation, with the excavation start having an offset from approximately one month in order to maintain the minimum distance of 25 m. Work was carried out in two shifts with a designated tunnel excavation crew with a minimum of 5 years of experience in similar ground conditions and a foreman to supervise the activities – all of whom were trained and qualified in-house personnel. Locally employed personnel were used for the removal of the excavated material and general logistics tasks. To deal with the local bear population all site installations had been fenced with a solid 2 meter high steel mesh. As well guards were placed 24/7. Despite all that measures several times a "Bear Alarm" was necessary but the "Visitors" left the site immediately after some horn signals of our heavy equipment.

Figure 5: Top heading excavation in sand and clay

Figure 6: Excavation of the invert

3.2 GEOLOGICAL CHALLENGES

3.2.1 Sand layers

During excavation, it became apparent that the sand layers were significantly thicker than predicted – up to full face conditions – and significantly more heterogeneous and less compacted than assumed. In particular, the narrowly graded, dry and almost binder-free sands caused very unstable face conditions [Figure 7] and breakthroughs in the crown and top heading areas.

As an immediate measure, the excavation length was reduced, the face was subdivided into smaller sections and full-face support consisting of reinforced shotcrete with 15 m long anchors was installed. Unavoidable overbreak's were filled with shotcrete as far as possible, additionally, to avoid possible cavities and to ensure that the primary lining was firmly attached to the mountain, injection drillings have been carried out subsequently in the back.

3.2.2 Clay / silt Layers

The clay and silt layers were described in the investigations as compact, cohesive soils of stiff to firm consistency, and in higher overburden also as clay/siltstone. In situ, irregular separation surfaces exhibiting slickenside structures [Figure 8] were frequently encountered, particularly in the Dacian sediments. The occurrence of slickensides led to a total loss of cohesion and to varying degrees of collapse behaviour of the excavation face. The cause of the slickensides is not of tectonic origin; it is assumed that they were caused by the swelling of clay minerals. Due to their relatively small size and irregular orientation, the structures could not be identified in the exploratory drillings.

The countermeasures were based on the thickness of the affected layers and included, in addition to a concentrated arrangement of face anchors with a minimum length of 15 m, the full-face securing with the reinforced shotcrete, as well as the reduction of the round length and excavation in smaller subdivisions.

Despite different causes, the effects and countermeasures were similar for both types of face instabilities. The necessary measures were identified and implemented independently by the excavation teams and, in most cases, could be carried out without interrupting tunnelling operations.

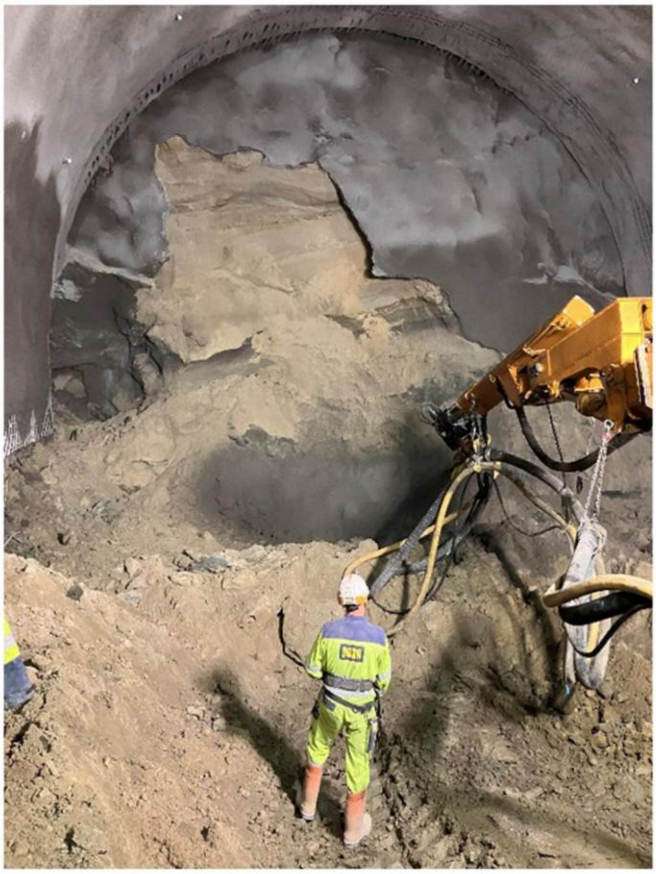


Figure 7: Face collapse due to sand during excavation of the bench

Figure 8: Slickensides in the face under clayey conditions (height of 45cm and a width of 30cm)

3.3 INCIDENT SHOTCRETE SHELL RUPTURE

On 3 April 2024, approximately 30 m behind the excavation face, there was unexpected spalling of the shotcrete shell and the opening of a longitudinal crack in the crown area. At this point, only minimal deformation had occurred. To prevent further deformation, additional self-drilling anchors were installed in the area around the crack.

Despite the measures implemented, the crack continued to propagate slowly, especially in the direction of the portal. Geotechnical measurements showed convergences in the range of approximately 0.5 cm/d. Up to that date, no significant deformations have been detected after the ring closure, but due to the low values in the measuring, no further precautions were taken apart from the continued anchoring.

After a period of stabilisation, on the evening of 6 April 2024, the crack extended from approx. 10 m to approx. 65 m within a short period of time [Figure 10] and the displacement also increased significantly. The cracking of the shotcrete was acoustically detectable and led to larger pieces of shotcrete breaking off.

In an ad hoc meeting with the foreman, supervisor, site manager, project management and the geotechnical engineer, it was decided to take immediate action and bring both tunnel drives to a controlled stop. At the same time, all preparations were made for large-scale anchoring in a 1.5 m grid with self-drilling injection anchors with a minimum length of 12 m throughout the entire top heading. Within 36 hours, approximately 3,500 running metres of anchors were drilled and injected using two drilling rigs, thus preventing further spread of the crack [Figure 9 and 11].

In the following days, after a damage analysis and several rounds of consultation with the designer and the geotechnical engineer, it was decided to install shotcrete ribs to stabilise the broken outer shell. The ribs were designed to be approximately 100 cm wide, reinforced in three layers, connected to the outer shell with shear dowels and installed at intervals of 7.5 m all around. In addition, a repair concept for the outer shell between the ribs was developed and implemented. The ribs were only gradually removed immediately before the inner shell was installed.

Figure 9: Repair work after the crack

Figure 10: Crack spreading in the top heading area

Figure 11: Anchoring after the crack appears

The approach and the measures decided upon were accompanied and fully supported by the client. The transparent communication that had already been practised throughout the entire construction period formed the basis for the trust in our actions that was necessary here.

4. RISK CONTROL MEASURES

4.1 STAFF

The excavation staff consists mainly of highly specialised skilled workers that are employed in the company for many years. The workers are all trained machine operators on the special equipment used in NATM tunnel driving and are able to react independently to any changes in the geology and take the appropriate conclusions for the tunnelling process. To achieve this, the workers receive regular external and internal training, e.g. on the tunnel construction technician course at the "Zentrum am Berg" of the Montanuniversität Leoben.

Together with the site management staff and the workshop personnel, around 75% of the personnel working in the tunnel are specialized tunnel operators.

4.2 GEOTECHNICAL CONSULTING

Although the contractor did not plan to provide a specialized geotechnical construction management for this project, experience has shown that soft rock tunnelling is characterised by greater geological and geotechnical complexity, so the construction company contracted a specialist geotechnical consultant to be permanently on site. The contract was designed to ensure independent consulting, documentation and risk assessment.

4.3 ORGANISATIONAL STRUCTURE

The organisational and management culture must be aligned with effective, efficient and, above all, low-risk work processes. This applies to all within the organisation and to the external stakeholders.

Internally, this means that regular operations must be managed with clear, consistent objectives, giving our specialist excavation workers the opportunity to respond to any deviations themselves but for sure under the supervision of experienced site engineers. At the same time, clear and rapid decision-making must take place in critical situations and the decisions made must be implemented rigorously.

In addition to the aforementioned high degree of technical specialisation, this requires above all a culture of appreciation and respect across all hierarchical levels, so that the entire team's expertise can be called upon immediately, impartially and without hindrance when needed.

With external stakeholders, a transparent error culture is particularly important, as is the definition and subsequent focus on the actual and common goal of completing the building on time, within the set quality and cost framework.

5. CONCLUSION

The project presented was characterised by significant deviations in the geology. In order to manage the geological risk, the approach of drastically reinforcing the tunnel secondary lining, which is otherwise common practice, was explicitly not chosen. Nevertheless, the excavation design came to the limits after reaching areas with unknown ground behaviour that caused unexpected loads and stresses on the shotcrete primary lining. The fast-developing deformations lead to significant damages that resulted in a risk of a tunnel collapse. Through the consistent use of highly specialised tunnelling personnel, intelligent engineering and a flat hierarchical structure of the site management, the complex project was successfully completed within the technical parameters set in advance. Successful in this case means that the joint focus of all parties involved on the result kept time losses to a minimum and resulted in a highly sustainable project in which only the technical needed and senseful elements had been used.

With a total time of 25 months from the start of the tunnel excavation to the completion of the secondary lining, it was once again possible completing a technically complex project on time using the NATM technology.

LITERATURE

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