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A case study of the TS-26 tunnel – the longest non-urban road tunnel in Poland using NATM technology

The article describes in detail the legal, technical and geological conditions faced by the designers and contractors of the TS-26 tunnel, located within the S3 expressway. The tunnel, which is the longest non-urban road tunnel in Poland, was constructed using the New Austrian Tunnel Construction Method (NATM). The project represented a considerable engineering challenge due to the geological conditions and the need to ensure the highest safety standards. The article describes the design process, including detailed geological analyses, and the construction phases of the tunnel, which included excavation, construction of the primary and secondary lining, and the installation of advanced safety systems. The TS-26 tunnel is a key element of the road infrastructure that will significantly improve communication in the region and support the economic development of Lower Silesia.

Key words: *tunnelling, tunnelling and tunnel construction, mining method of tunnelling*

1. INTRODUCTION

The beginning of the 21st century brought about the dynamic development of road transport networks and infrastructure construction in Poland. Alongside these developments, a special branch of underground construction began to develop, allowing roads to be run smoothly under terrain obstacles.

The construction of more than a dozen road tunnels has been successfully completed, including the tunnel under Świna River in Świnoujście, the tunnel under the Martwa Wisła in Gdańsk, the Emilia tunnel in Laliki, and the TS-26 and TS-32 tunnels along the S3 expressway, with others along the S1 or S19 expressways currently under construction, to mention just a few examples.

Regarding the techniques used for tunnelling, the most commonly used are: open-cut methods, mining methods and special methods (including the shield method, which is becoming increasingly popular in Poland) [1]. The choice of tunnelling method depends on a number of factors, i.e. hydro and geological conditions and the characteristic parameters of the tunnel to be designed, especially the length and required clearance, but also the installations and devices of the tunnel equipment.

An example of a tunnel excavated using the mining method is the TS-26 tunnel, which was opened on 31 July 2024. The tunnel was constructed using the *Neue Österreichische Tunnelbaumethode* (NÖT) or New Austrian Tunnelling Method (NATM for short), which was formulated by Prof. Ladislaus von Rabcewicz in 1948. The main advantage of this method is its versatility with regard to the required shape of the excavation and the dimensions of its cross-section. A characteristic shared by all mining tunnelling methods is the phased nature of the tunnelling process, with the main division being the excavation and construction of the primary lining and the erection of the secondary lining, also known as the final lining. The philosophy behind NATM is that the rock mass is the load-bearing element and can deform freely, and the ongoing monitoring of its behaviour allows for dynamic adjustment to the conditions encountered.

The basic principle of NATM technology is to make the best possible use of the self-supporting effect of the rock mass, which is a fundamental element of primary lining. In order to meet this condition, it is crucial to properly excavate the rock to use the natural stress distribution [5].

Depending on the characteristics of the rock mass, the parameters of the primary lining components, such as the thickness of the shotcrete layer (shotcrete) and the degree of its reinforcement (steel mesh or steel fibres), the number of rock anchors and the spacing of the steel lattice girders are adjusted to the local conditions, based on ongoing geotechnical monitoring (observational method [2]).

In a subsequent stage of the works, as soon as the excavation has been completed, the primary lining has been constructed and settlements have stabilised, the reinforced concrete inner lining of the tunnel is built [5, 6].

2. SITE CHARACTERISTICS

The TS-26 tunnel structure consists of two main tubes (approximately 2,300 m long), connected by eight emergency cross passages (spaced at intervals of up to 250 m) and one emergency crossing for vehicles located in the centre of the tunnel.

In each of the tunnel tubes, there are alarm points – equipped with emergency telephones and fire extinguishers – and firefighting niches – where hydrants are located, which are an important element in ensuring safety in the tunnel. In addition, the tunnel is equipped with a number of installations and safety systems such as emergency lighting, longitudinal ventilation, systems for fire detection and warning, monitoring and detection, traffic control and monitoring, radio communication for emergency and maintenance services, sound and telephony for maintenance staff, as well as an automatic tunnel control and management system.

3. PROJECT ASSUMPTIONS

The start of the TS-26 tunnel was preceded by an analysis of the geological conditions and the development of a detailed design. The construction area is situated at the interface between two geological units: the Kaczawskie Mountains metamorphic complex in the north and sediments of the Central Sudetic Depression in the south (Fig. 1).

For the preparation of the geological model, 48 test boreholes were drilled, at depths ranging from 11 to 70 m, with a total length of more than 1,900 m. In addition, 13 dilatometric surveys were carried out and included three boreholes.

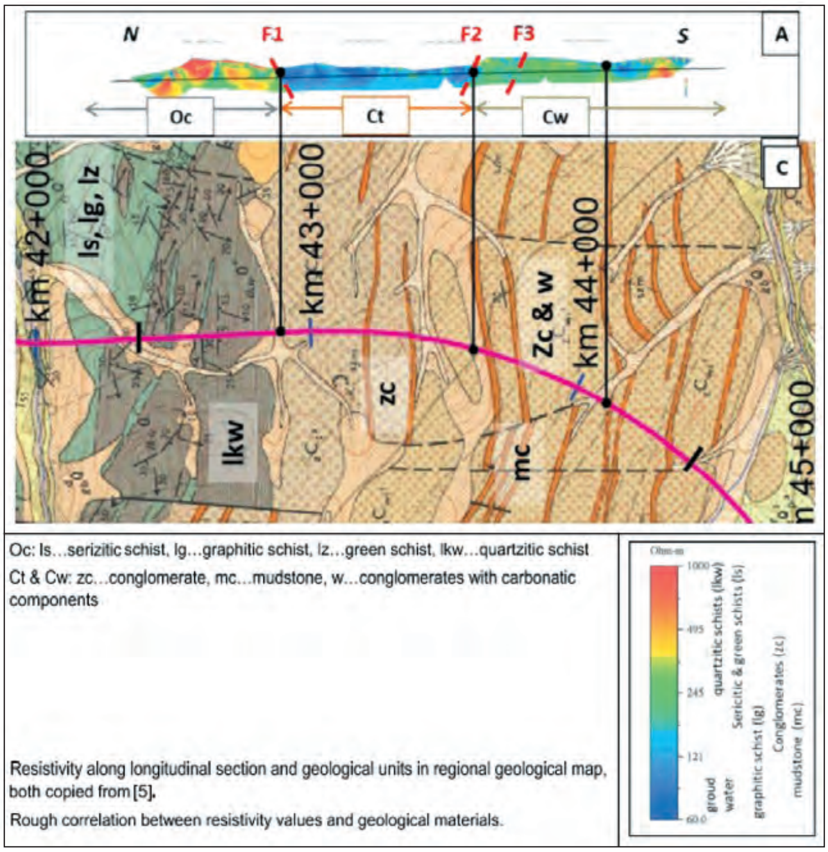


Fig. 1. Geological cross-section – overview [3] after [5]

Rocks encountered along the line of the tunnel routes (from N to S) included Ordovician schist (related to the Oc Kaczawskie Mountains) and Carboniferous conglomerates, sandstones and greywacke sandstones (deposited in the synorogenic Ct and Cw Depression). Following the new surveys, the definition of ground types for the rockmass was extended and their values were adjusted to the corresponding characteristic properties.

Based on the new boreholes and the archival data provided by the Client and the regional geology documentation, six ground types were defined – O1 to O3 for Ordovician shale (unit Oc) and C1 to C3 for Carboniferous sediments (units Ct/Cw = C*) (Figs. 2, 3).

On the basis of the exploratory boreholes and interpretation of the acquired data, a complete three-dimensional geological model of the rock mass was created, which was used for all further calculations, in the course of which four main classes of primary lining of the excavation were determined, ranging from class A, which is the lightest class used in the most favourable ground conditions, to D – the heaviest class of lining.

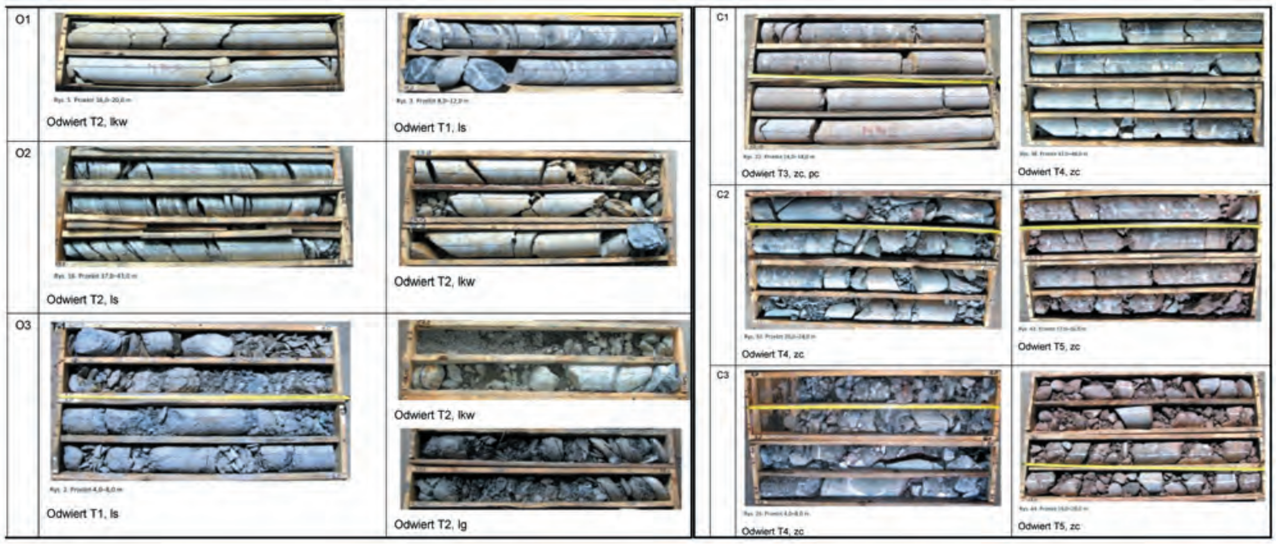


Fig. 2. Typical appearance of ground types O1, O2 and O3 (left), and C1, C2 and C3 (right) in the borehole cores [3]

Ground type *Typ gruntu*	Rock type *Typ skały*	Characteristics RQD *Charakterystyczne RQD*	Standard classification *Standardowa klasyfikacja*	Density *Gęstość*	Cohence *Spójność*	Fraction angle *Kąt tarcia*	Rockmass strenght *Wytrzymałośc górotworu*	Deformation modulus *Moduł deformacji*	Elasticity modulus *Moduł elastyczności*	Poissons' ratio *Współczynnik Poissona*	At-rest earth pressure *Ciśnienie gruntu w stanie spoczynku*
GT		RQD	GSI	ρ	c	φ	UCSrm	D	E	ν	k0
		[%]	[–]	[g/cm^3]	[MPa]	[°]	[MPa]	[GPa]	[GPa]	[–]	[–]
O1	schist unit *jednostka łupka*	>50	40–55	2.6	1.500	30	5.2	3.0	6.0	0.25	0.33
O2		25–50	20–40	2.6	0.400	21	1.2	1.5	3.0	0.30	0.43
O3		<25	?20	2.5	0.150	14	0.4	0.3	0.6	0.35	0.54
SO		–	–	2.1	0.010	25	–	0.1	0.1	0.35	0.58
C1	conglomerate unit *jednostka zlepieńca*	>50	50–60	2.6	2.500	35	9.6	3.0	6.0	0.20	0.25
C2		25–50	35–50	2.6	1.200	35	4.6	1.2	2.4	0.25	0.33
C3		<30	15–35	2.5	0.020	35	0.1	0.2	0.4	0.35	0.43
SC		–	–	2.1	0.010	28	–	0.1	0.1	0.35	0.53

Fig. 3. Adopted soil types [3]

4. EXECUTION TECHNOLOGY, LEGAL CONDITIONS AND WORK STAGING

The basic principle of the New Austrian Tunnel Construction Method (NATM) is to try to use the effect of the self-supporting rock mass, which is the basic element of the primary lining, as much as possible. For this to be possible, it is important to continuously monitor the geological and geotechnical ground conditions encountered. It is crucial to properly excavate the rock to make use of the natural stress distribution. At the same time, it is important to successively construct a primary lining of shotcrete, reinforced (with steel mesh or fibres) as the work progresses [4].

The NATM method foresees the construction of the tunnel in two basic stages:

- excavation and construction of the primary lining (Geological and Mining Law [7]),
- execution of the secondary lining (Geological and Mining Law [7] / Construction Law [8]).

Bearing in mind the provisions of Art. 2, para. 1 of the Construction Law and Art. 2, para. 1 pt. 4 of the Geological and Mining Law and the chosen method of excavation using mining technology, the commencement of the work of excavation and construction of the primary lining of the excavation was preceded by the opening of a mining plant, within which a mining plant operation manager was nominated, and a traffic plan and organisational structure developed. In the next stage, the plant's traffic plan was approved by a decision of the Director of the Regional Mining Authority.

Finally, excavation started on 5 December 2020 at the south portal in the east tube. The work took place in parallel cycles in four faces of approximately 150 m^2 each, on a 24-hour, 7-day-a-week basis. The lengths of the cycles (rounds) and the type of support class chosen depended on the geology encountered. There were 4 main classes (from the lightest A, used in the most favourable ground conditions, to D, the heaviest) of lining and 4 sub-classes within each of the main classes (10–40), (Figs. 4–6).

The first stage was the drilling of blast holes (Fig. 7), followed by the setting of explosive charges (Fig. 8), and then the blasting and removal of the excavated material. The excavation was immediately secured using lattice girders, steel mesh and sprayed concrete (Fig. 9). Continuous geological (Fig. 10) and geotechnical (Fig. 11) monitoring was carried out during the works, allowing for the ongoing assessment of the ground conditions encountered and the proper selection of the support class.

When unfavourable geological conditions were encountered, the blocky nature of the rock mass and the need to stabilise the excavation and ensure the safety of the workers, rock anchors were also installed in the face and, in the case of poor ground conditions, pipe roof umbrellas were used, the number and distribution of which depended on the class of primary lining. The excavation of the two tunnel tubes and the execution of the primary lining was completed with the breakthrough on 22.02.2022.

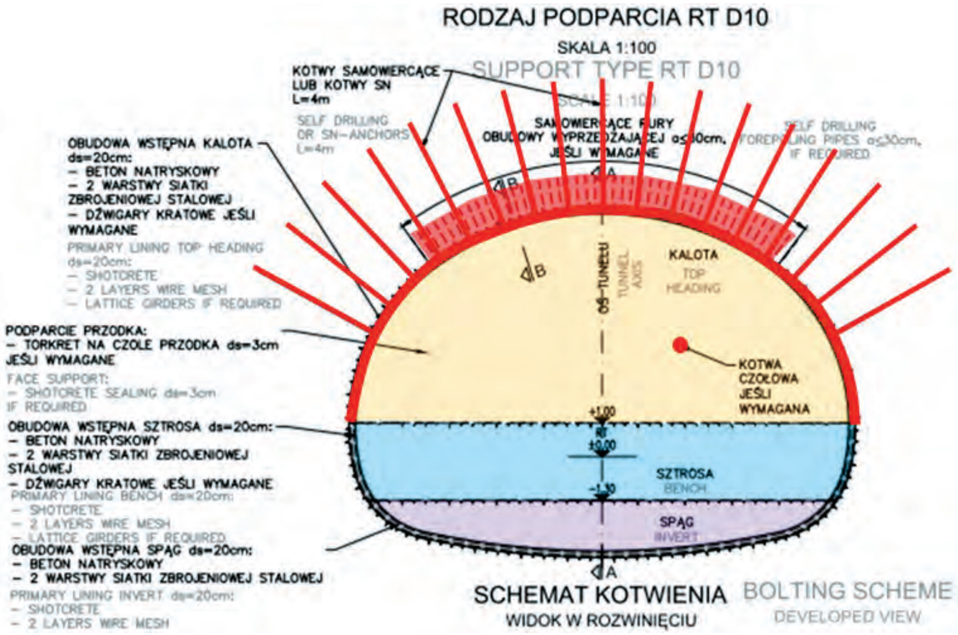


Fig. 4. Support class D10, cross-section of pit division with elements of primary lining [3]

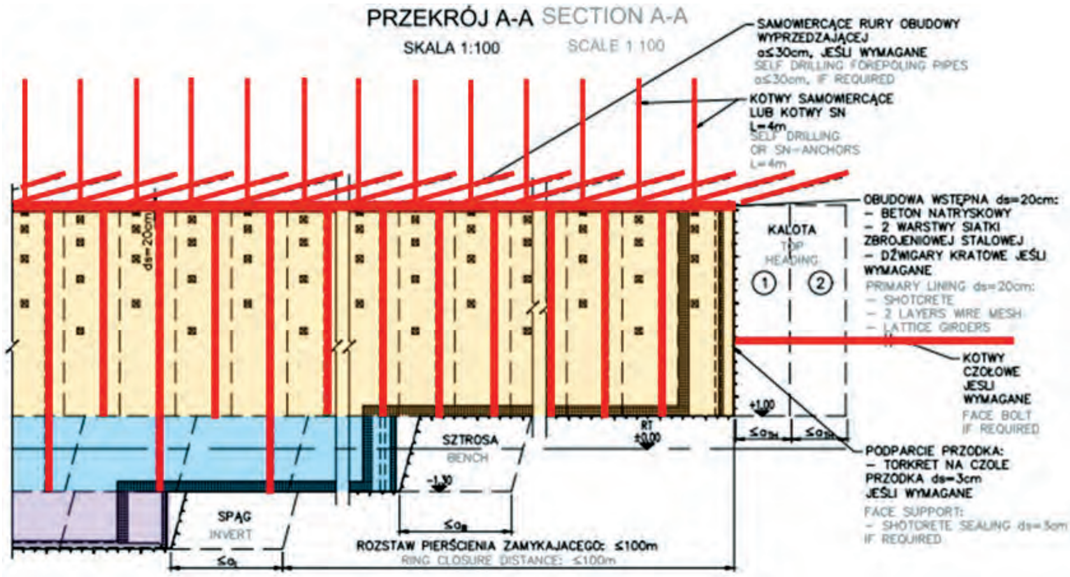


Fig. 5. Support class D10, cross-section A-A of a pit subdivision with elements of the primary [3]

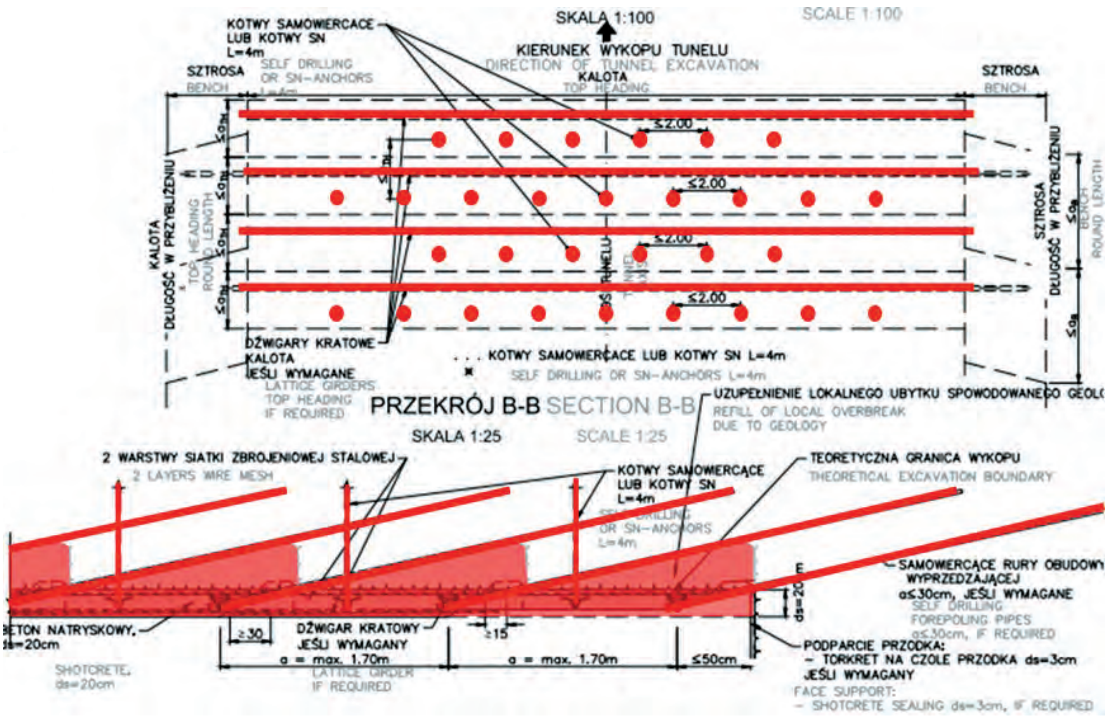


Fig. 6. Support class D10, anchoring plan – layout [3]

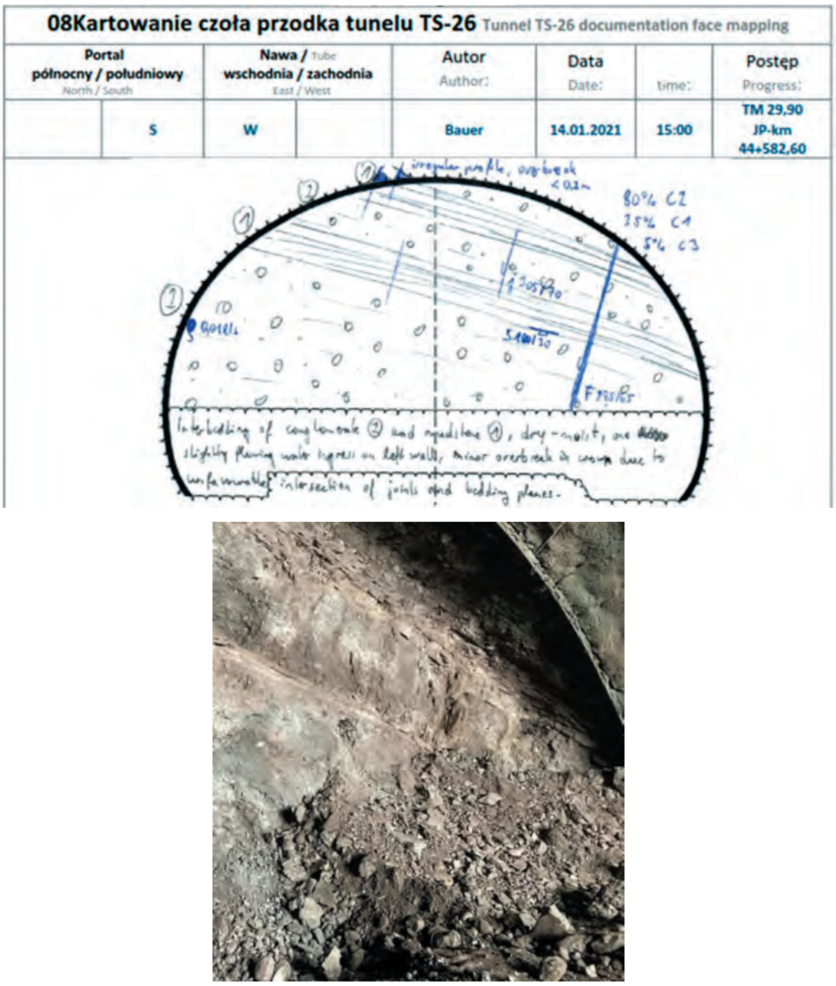
Fig. 7. Drilling of blast holes [3]

Fig. 8. Setting up explosives [3]

Fig. 9. Execution of primary lining (here: installation of rock anchors) [3]

a)

b)



08Kartowanie czoła przodka tunelu TS-26 Tunnel TS-26 documentation face mapping							
Portal północny / południowy North / South		Nawa / Tube wschodnia / zachodnia East / West		Autor Author:	Data Date:	time:	Postęp Progress:
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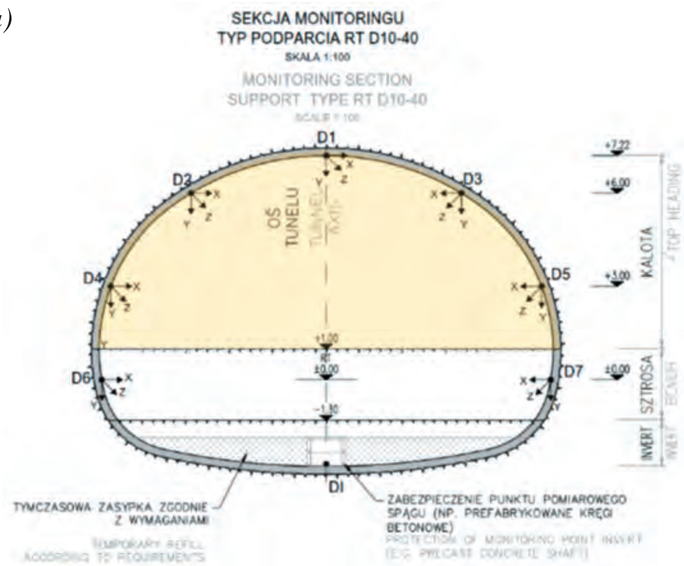
Fig. 10. Geological monitoring: a) geological documentation of face mapping; b) photographic documentation [3]

a)



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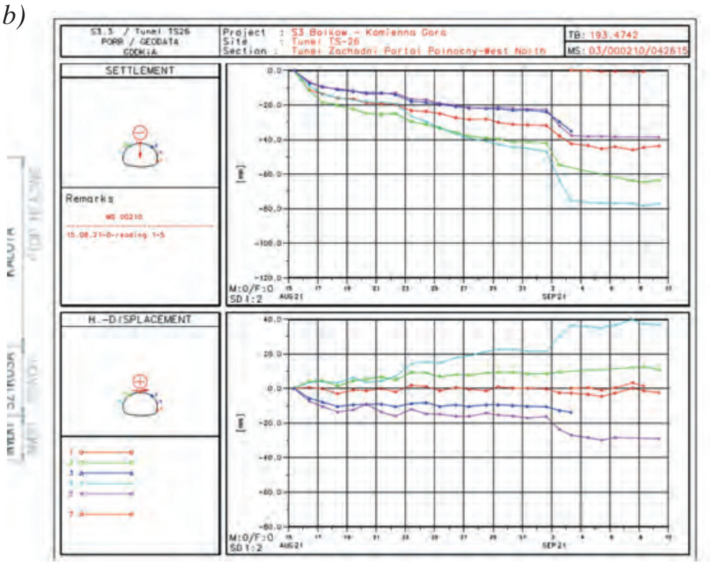

Fig. 11. Geotechnical monitoring: a) layout of monitoring sections; b) geotechnical report [3]

The next stage of the work was preceded by the successive handover of the tunnel by the mining plant's operations manager to the site manager. During this time, the mining equipment and installations were dismantled and a levelling layer of unreinforced shotcrete was made over the entire excavation arch. A technological road made of rolled compacted concrete (Fig. 12) along the entire length of both tunnel tubes and technological installations were also prepared.

Fig. 12. Tunnel after completion of excavation, completion of the shotcrete levelling layer and technological road [3]

Prior to the beginning of the main works related to the realisation of the reinforced concrete inner lining, reinforced concrete invert slabs were made in sections where the parameters of the rock mass were unfavourable, as well as reinforced concrete foundations (abutments) of the blocks of the inner lining of the tunnel, which also functioned as foundations for the track of the technological gantries – insulation, reinforcement, formwork and repair.

In the next step, a waterproofing layer consisting of a geotextile and a welded PVC membrane (Fig. 13) was constructed, as well as the sidewall drainage which was built into a layer of filter concrete.

In the next stage, the installation of the inner lining reinforcement began and which was carried out using reinforcement gantries equipped with platform lifts to make it easier to move the reinforcement packages. Concrete work began on 8 May 2022 with the execution of the first block of the tunnel's inner lining, outside the excavated section, in the open-cut section at the north portal. Each of the inner lining blocks was 12.5 m long, with a total of 369 of them constructed along the entire length of both tunnel tubes. The first of the inner lining blocks for the excavation was completed on 29 May 2022, and all the inner lining work for the tunnel's main tubes, as well as the cross passages, emergency passage for vehicles and maintenance niches, firefighting niches and alarm points, was completed 356 days later. Concrete was poured using a formwork gantry equipped with a piping system (Fig. 14).

The execution of all the inner lining works consumed more than 100,000 m^3 of concrete, produced at the on-site concrete batching plant.

The completion of the works did not, however, complete the object. Further steps included the completion of reinforced concrete pavement slabs with cable ducts, road layers, safety and traffic control installations and systems.

Fig. 13. Execution of waterproofing: geotextile protective layer, PVC membrane [3]

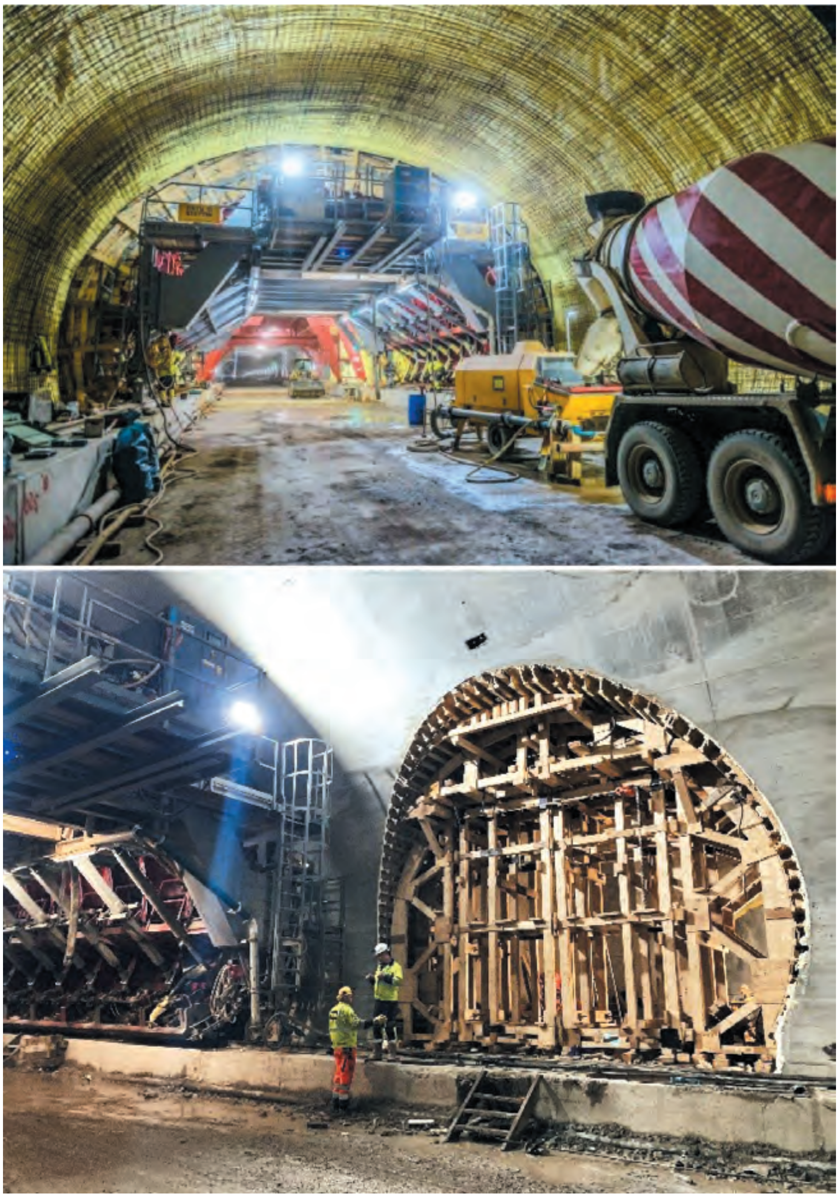

Fig. 14. Installation of reinforcement and formwork gantry [3]

5. SUMMARY

NATM technology is a very flexible method and, because of its sequential nature, offers the possibility of constant adaptation to diverse, sometimes complicated hydrogeological conditions, where anticipating rock mass parameters is difficult.

However, it is not a perfect method, requiring excellent site organisation, continuity of supply and maintenance and, above all, a high degree of coordination and interprofessional cooperation at each stage of the work. Each stage of construction must be precisely planned and coordinated to ensure the safety and efficiency of the project.

The construction of the TS-26 tunnel is an excellent example of cooperation between two important engineering disciplines: mining and construction, but also geologists and surveyors. This project demonstrates the importance of integrating knowledge and expertise from different disciplines to meet technical and logistical challenges. Thanks to the commitment and cooperation of many specialists, it was possible to realise this ambitious project.

In conclusion, the TS-26 tunnel is not only an important piece of road infrastructure, but also an example of modern technology and effective engineering cooperation.

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