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UNCERTAIN OUTCOMES OF GEOTECHNICAL WORK ILLUSTRATED WITH THE EXAMPLE OF A ROAD TUNNEL

NIEPEWNOŚĆ W REALIZACJI PRAC GEOTECHNICZNYCH NA PRZYKŁADZIE TUNELU DROGOWEGO

A b s t r a c t

This paper presents a number of factors which influence the design and construction of a geotechnical structure, i.e. a road tunnel. For this type of structure, it is necessary to thoroughly examine the geological conditions and the properties of the rock mass. Research carried out on the basis of drilling gives only local results, which consequently only provides an estimated description of the characteristics and properties of the rock mass.

Keywords: geotechnics, road tunnel

S t r e s z c z e n i e

W artykule przedstawiono wybrane czynniki wpływające na proces projektowania i realizacji obiektu geotechnicznego jakim jest tunel drogowy. Ze względu na charakter obiektu niezbędne staje się dokładne rozeznanie warunków geologicznych i własności ośrodka skalnego. Badanie z wykorzystaniem otworów wiertniczych jest jedynie punktowe, co w konsekwencji prowadzi do szacunkowego opisu cech i własności masywu skalnego.

Słowa kluczowe: geotechnika, tunel drogowy

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1. Introduction

In order to construct road engineering structures such as tunnels, it is necessary to carry out geotechnical work. The tunnel structure, in the form of the tunnel lining, interacts with the rock mass over its entire circumference and along the whole length of the tunnel. Therefore it is necessary to carry out a thorough examination of the geotechnical conditions present around the tunnel [2].

Taking the type of engineering structure into account, the required scope of rock mass examination encompasses, in most cases, the geological structure, hydrological conditions and characteristics of each particular lithostratigraphic unit, as well as the characteristics of the rock mass itself. Research methods include research excavation, core drilling and geophysical methods. Research excavation enables researchers to determine the exact lithology and characteristics of the rock mass, while sampled material is used for detailed analysis of its physical and mechanical properties. However, this method has some drawbacks: it is quite time-consuming, and the depth of the excavation is usually limited to a few meters. When deeper tunnel's foundations are planned, it is necessary to carry out core drilling. This provides the precise lithology of the rock mass. The sampled core is used in laboratory analysis. The number of drilling points performed along the entire length of the planned tunnel is usually limited; therefore, data gathered during this research is usually only local. Moreover, if the core is considerably broken up, only a small number of samples are obtained for the analysis of the mechanical properties of the rock, and as a consequence researchers can only make approximate determinations [4].

In the case of geophysical methods, the entire area through which the tunnel will extend can be covered by the survey and, in most cases, research is performed for the entire area. Undoubtedly this is very advantageous, but it must noted that this kind of research is less precise and thus the analysis can only provide estimated data.

We can therefore conclude that difficulties in assessing the lithology, properties of rock strata and characteristics of the rock mass around road tunnels pose the greatest problems during a project's design and construction. Geotechnical projects in which the methods used for the design and construction processes depend mainly on the characteristics of the rock mass are subject to great uncertainty and, consequently, to high risk. This risk presents itself in three areas: environmental, technological and economic (Fig. 1).

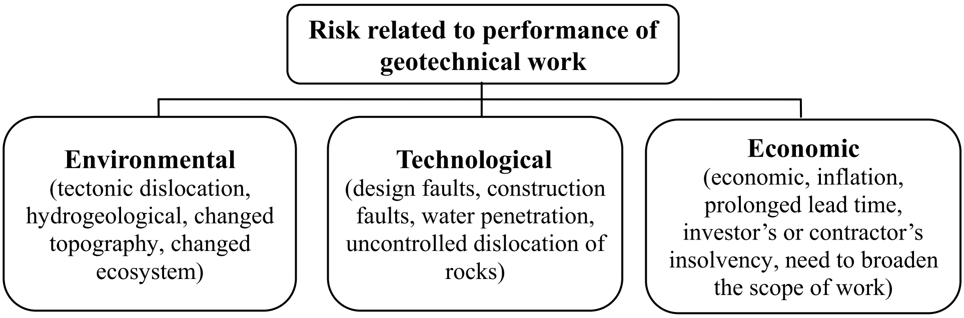

Fig. 1. Risk related to the performance of geotechnical work

2. Methods for designing underground structures

Due to the specific characteristics of tunnels and most of all as a result of the unique geological conditions present in various places, general schemes with general instructions are commonly used during the implementation phase. The New Austrian Tunnelling Method (NATM) is the most common practice [5]. The whole procedure consists in taking the greatest possible advantage of the geological strength available in the surrounding rock mass while tunnelling. In order to achieve this goal, an active initial and final lining is constructed, which interacts with the rock mass soon after its construction. Usually this lining takes the form of shotcrete, which if necessary is reinforced with a lattice girder and mesh, as well as anchors. As it is placed shortly after consecutive face advances, it is possible to minimise dislocations in the surrounding rock mass and to limit the range of cracking. Moreover, the rapid construction of the lining over the entire circumference of the tunnel also contributes to achieving this goal. The structure of the initial lining is monitored in order to apply necessary reinforcements when anticipated dislocation and load occur. Depending on the current condition of the rock mass, one of the previously designed reinforcement schemes is implemented. However, such reinforcement options are considered to be recommended guidelines rather than rigidly enforced solutions. When deformations in the initial lining occur, the final lining is constructed.

Generally, in designing underground structures, so-called standard methods are used, i.e. commonly known analytical, numerical and complex methods [3]. These are used depending on the results gathered during field surveys (Fig. 2).

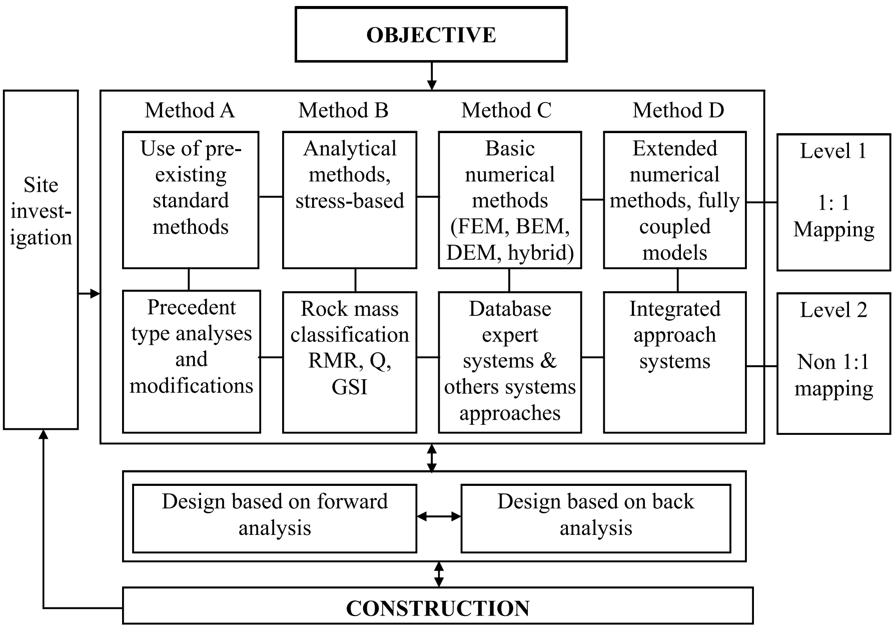

Fig. 2. Flowchart for rock mechanics model ling approaches

3. Example of road tunnel construction

3.1. Tunnel design

The road tunnel in Laliki, commissioned in 2010, is the first of three planned tunnels along the S-69 road between Żywiec and Zwadroń; the other two will be located in Milówka and Węgierska Górka. The modernisation plan for this road section was first developed in the mid-1990s [6]. In subsequent years, consecutive documentations and studies were developed, in which the scope of modernisation and the range of necessary geological and engineering research were determined in more detail. The conceptual design study for the road tunnel in Laliki was prepared in 1998 [9]. Geological and engineering research was carried out between 1996 and 2000, covering core drilling, seismic analysis, electrical resistivity tomography, research excavation, surface charting, and geodetic observations of rock mass dislocations within the area surrounding the portals [1]. Thanks to these surveys it was possible to determine the geotechnical classification of the rock mass to be cut during tunnel construction, enabling engineers to prepare the technical design. In 2006, geological and engineering characteristics of the rock mass were determined for nine specified sections. The results of these surveys concluded that features of the rock mass were extremely diverse in terms of lithology and rock strata inclination, as well the physical and mechanical properties the rocks. It must, however, be noted that complete data was not gathered for all sections, exemplifying the above statement that it is practically impossible to carry out detailed examinations of the properties of rock masses in the case of underground structures.

On the basis of the rock mass data which was gathered, engineers were able to develop four versions of the initial lining, made from shotcrete reinforced with lattice girders and steel mesh. Moreover, the rock mass was reinforced with steel anchors (Table 1). A type-1 lining was designed for the most advantageous conditions, a type-4 for the worst. An evacuation tunnel was designed 30.7 m away from the road tunnel axis. The tunnel's external dimensions measured 13.48 m wide, 9.50 m high. The scheme of type 4 lining is presented in Fig. 3.

Table 1

Specifications of the primary lining scheme

Type of protection	Type of lining			
	1	2	3	4
Shotcrete	180 mm	200 mm	250 mm	300 mm
Lattice girder	70/20/30	70/20/30	95/20/30	95/20/30
Steel mesh	1 × 6/150/150	1 × 6/150/150	2 × 6/150/150	2 × 6/150/150
Resin bolts	4 m	4 m	4 m	4 m
Self-drilling anchors	–	6 m	6 m	6 m

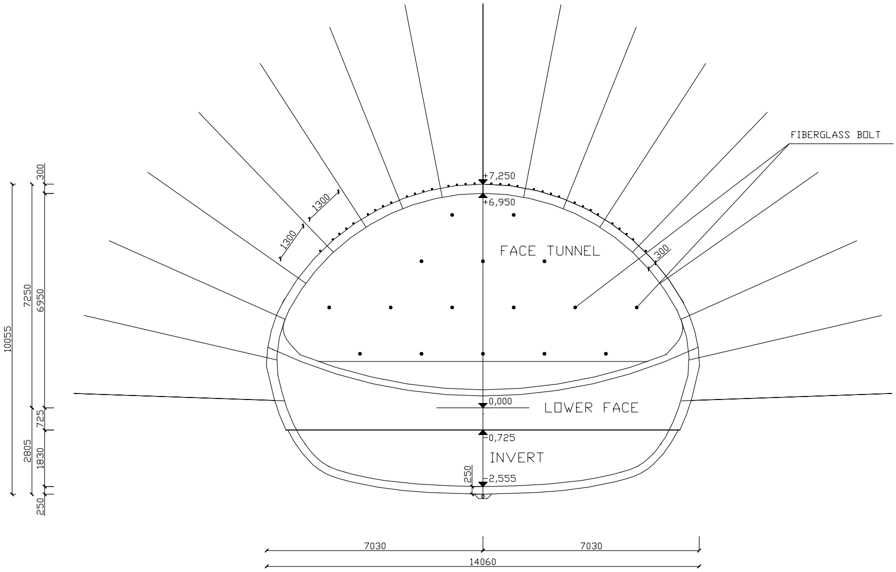

Fig. 3. Cross section of the tunnel in Laliki – type 4

3.2. Tunnel construction

The winning tender was selected in 2007 and by November of that year, construction work had already commenced. The contractor's duties encompassed the construction of a section of road 4.7 km long, including a 678-metre tunnel. It was estimated that construction of the tunnel would cost 122.6 million PLN, whereas provision of equipment would amount to 24.6 million. Tunnelling commenced from the southern portal and was carried out in compliance with general NATM guidelines. Tunneling was performed in two stages: the crown section of the tunnel was drilled first, after which the floor was prepared. For the most part, mining was performed mechanically, with explosives being used only occasionally. In order to determine the current properties of the rock mass, geological and engineering analysis were carried out following each face advance. This analysis included determination of lithology, strata inclination, rate of weathering, strength rate, RQD rate, discontinuities in density, the characteristics of such discontinuities, rock blocks, and hydrological conditions. On the basis of these results it was possible to determine the rock class for the subsequent face advance. At the same time engineers were able to specify the type of lining to be constructed. Altogether approximately 600 charts of the crown section were performed in the tunnel face, supplemented each time by photographic documentation.

Preparation of such detailed documentation was necessary during the construction phase because, as can be seen in the following diagram, the share of lithological strata observed along the tunnel and analysed in sections approximately 5 m long were very divers (Fig. 4). On the basis of the diagram it can be concluded that within several meters, the lithology observed could differ significantly. At the same time it must be emphasised that an increased share of sandstone in the tunnel cross-section contributed greatly to the stability of the surrounding rock mass; consequently it was possible to construct the lining with a lower load capacity which was cheaper.

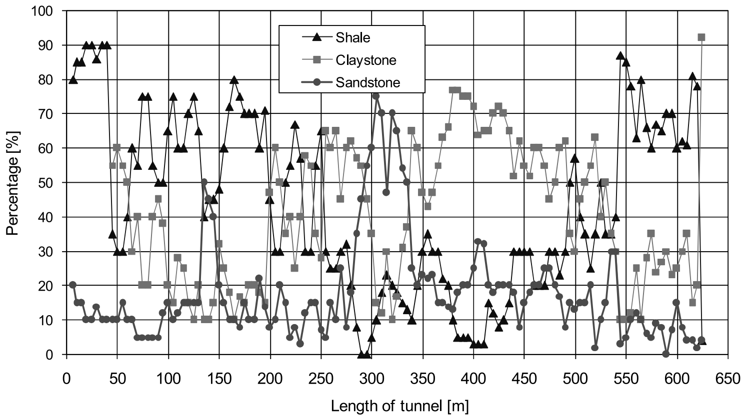

Fig. 4. Change of lithology in tunnel length

In certain sections of the tunnel, however, the poor quality rock mass raised concerns that the area might lack stability or that a possible roof collapse might occur. Such incidents sometimes occur and the resulting costs are then far greater than those related to constructing a lining with a higher load capacity. During the course of the ongoing analysis of rock mass properties it was decided that micropile reinforcement needed to be constructed in some sections of the tunnel; in such sections, the lining was marked as type 5 (Fig. 5). Forepoling is frequently applied for tunneling in difficult geotechnical conditions [10, 12].

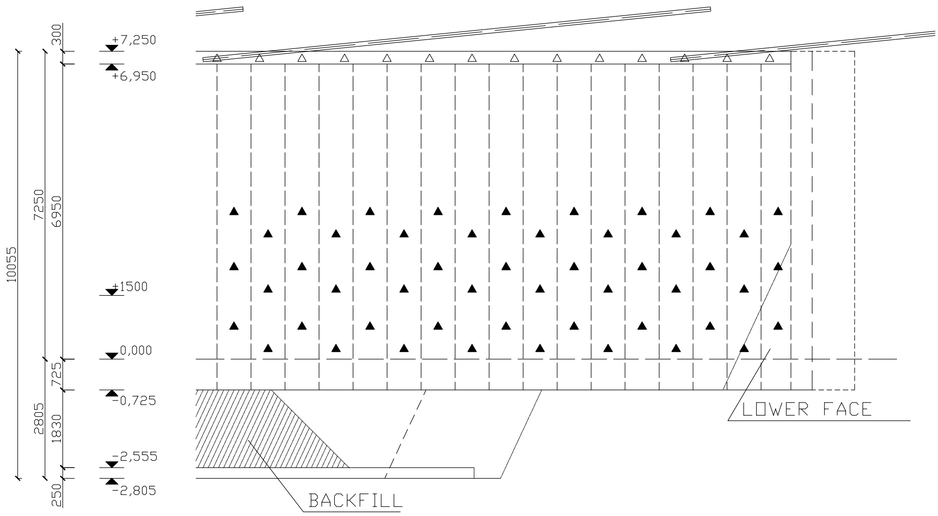

Fig. 5. Scheme of lining – roof protected with forepoling, type 5 (Majcherczyk et al. 2012)

Although solutions of this kind are expensive, they are often used in difficult conditions; however, this solution was not included in the investor's design and therefore was the subject of a long discussions between the contractor and the investor. Once it was determined that this kind of lining would be constructed, tunneling was not further delayed by such considerations. During the tunneling process a number of measurements were taken to monitor the performance of the initial lining, including convergence. At times it was necessary to introduce certain changes to the construction technique for the initial lining. These changes were determined on the basis of dislocation of the initial lining contour in relation to the technical design. Table 2 presents permissible and measured dislocations, along with the length of sections which were to be constructed with a particular type of lining and for which the planned type of lining was actually constructed. The results presented in the table conclude that measured convergence was considerably greater than the permissible levels, and the final load capacity of the lining was greater than initially designed. Tunneling was completed in May 2009; in March 2010 the tunnel and the road section were officially commissioned.

Table 2

Expected and actual convergence and length of sections protected with particular types of lining

Type of lining	Permissible convergence of initial lining [mm]	Measured convergence of initial lining [mm]	Length designed to have a particular type of lining [m]	Length constructed with a particular type of lining [m]
Type 1	30	–	47.25	–
Type 2	40	56	98.75	37.5
Type 3	60	60.9	138.6	197.95
Type 4	60	168.8	345.5	204.9
Type 4a	60	136.1		
Type 5	80	205	–	189.6

4. Conclusions

Based on the analysis of geotechnical work performed in relation to the construction of the road tunnel using the mining technique, it is possible to draw the following conclusions:

1. Construction of road engineering structures, including tunnels, is subject to a high level of environmental, technical and economical risk. Each of these factors include highly unpredictable elements which can cause great uncertainty during the performance of geotechnical work;
2. In order to develop a technical design, it is necessary to carry out extensive research on the geomechanical properties of the rock mass. This research is expensive and time-consuming, but its reliability increases with the number of measurements taken;
3. Even if the scope of the rock mass survey is very extensive, it cannot, however, guarantee that the technical solutions will be always efficient. Due to the fact that hydrogeological conditions are diverse and unrepeatable, a number of modifications need to be introduced during implementation of the project;

4. The implementation of geotechnical projects must be carried out with agreed mechanisms for cooperation, and risks related to implementation of the project must be adequately distributed between the contractor and the investor. Variable geotechnical conditions, different from those anticipated in the design study, require prompt and resolute decisions; otherwise project implementation can be delayed or disrupted, possibly leading to dire consequences.

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