STATE ANALYSIS OF CONSTRUCTION OF DERIVATION TUNNEL IN HERZEGOVINA

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Summary: *Tunnels are specific objects, built under the ground surface, in order to overcome some of the obstacles and may be classified as the most complex engineering structures for traffic and transport, connecting the two segments separated by a barrier. The paper presents an analysis and comparison of methods of tunneling for the needs of hydro power plant "Dabar" in Nevesinje. The analysis is based on a project-technical documentation of derivation tunnel and previous theoretical and practical studies and works. The aim of this work was to study and analyze various methods of tunneling (NATM, TBM method) and compare their characteristics in order to propose optimum method of excavation for this specific object. Based on the analysis of the state of construction (site characteristics) the best solution and a combination of solutions of derivation tunnel excavation for the purposes of hydro power plant have been analysed and theoretically proposed.*

Key words: *Tunel, methods, excavation, solution, analysis*

1. INTRODUCTION

Under the method of tunnel construction, we consider excavation method, way of ensuring the stability of the tunnel openings through temporary or permanent support units and coverings. In a preliminary or final stage, following factors influence the choice of method of construction:

- engineering geological and geotechnical conditions,
- height of overlayer,
- the size of cross section,
- tunnel length, and
- technological conditions.

The methods of construction can be divided into three main groups as follows:

- Classical methods
- Modern methods
- Special methods

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Regardless of the choice of a particular method, following main differences can be emphasized:

- Classical methods - rock mass at the excavation is significantly disrupted, and there are significant out-of-profile redundancies, support elements are carried out with a wooden structure, a profile is poorly passable for larger vehicles.
- Modern methods - rock mass is not disturbed, and the profiles are correct, support units arenot in the profile, than in the rock.

The aim of this work was to study and analyze various methods of tunneling (NATM, TBM method) and compare their characteristics in order to propose optimum method of excavation for this specific object. Based on the analysis of the state of construction (site characteristics) the best solution and a combination of solutions of derivation tunnel excavation for the purposes of hydro power plant have been analysed and theoretically proposed.

2. NEW AUSTRIAN TUNNEL METHOD (NATM)

This method is based on an entirely new philosophy of behavior and phenomena around tunnel openings, as well as the application of new material. Basic characteristics and differences compared to conventional methods are as follows:

- After the excavation, primary tunnel structure is immediately built. It is not rigid as in conventional methods, but "flexible" and allows deformation of the surrounding rock, causing reallocation of output stresses, and thus relaxation of rock. This results in a significant reduction of pressure.
- The surrounding rock mass takes on part of the pressure, with the so-called the supporting ring, which is formed by installing anchors.
- The stability of primary structure is controlled with measurements, and when a further increase in deformation stopped, a secondary covering is being built.
- Application of sprayed concrete and anchors as new materials in tunnel construction [1].

3. TBM METHOD (TUNNEL BORING MACHINE)

Tunnel excavation in stable, hard and solid rock mass is usually carried out with the explosives, and lately more and more mechanical excavation in the full profile is being applied, using rotating machinery, mole (TBM - Tunnel boring machine).
When using excavation explosives, it is necessary to execute a sequence of successive, separate operations such as drilling, blasting, ventilation, removal of unstable blocks, loading and transport. These operations can not be carried out in parallel, especially under harder conditions. In addition, mining has other disadvantages, such as danger during mining, large rock mass distraction and possible large canals and the need for subsequent enlargement (additional excavation).
TBM method involves a machine for digging tunnels, usually in the full profile of circular cross-section with a large "head" for digging, which can penetrate through all types of soil. Sizes of these machines range from one meter up to 20m in diameter [2].

4. COMPARATICE ANALYSES OF METHODS: DRILL AND BLAST – NEW AUSTRIAN METHOD AND TBM

The use of TBM method is much higher in the world (especially in developed countries) and more pronounced during the excavation of a relatively long tunnels. Using conventional method D&B is almost limited to the excavation of short tunnels and tunnels with irregular and variable cross section. Based on the research and analysis, it can be concluded that the application of D&B is relatively cost-effective methods for tunnels length up to 2 km. However, the length of the tunnel is not the only parameter to be considered. In each case, it is necessary to compare all the requirements related to tunnel excavation and preparation, such as: the axle shape, longitudinal gradients, forms of cross-sections and natural composition of the terrain or physical-mechanical properties of rock material through which the canal is performed [3]. Advantages and disadvantages of these two methods are given in Table 1.

Table 1 - Advantages and Disadvantages of D&B and TBM excavation methods

	D&B	**TBM**
Advantages	Possible various cross-sections of the tunnel Equipment from one tunnel can be used again Easy maintenance Low installation costs Adaptable to changing properties of rocks	A cost-effective method with long tunnels Quick construction of a tunnel Good substrates (without irregularities) in the rock mass Safety at work acceptable Suitable for soft rock
Disadvantages	Safety at Work Small Excavation is limited to approximately 8 m per day Necessary a good and complicated tunnel structure Construction costs are changing with the changing composition of the rocks, it is difficult to accurately predict the cost of construction	Possible to perform a circular cross-section of the tunnel The high cost of building construction Jamming machinery resulting in long delays and unforeseen costs Complicated application in the field, rocks with variable characteristics and properties

In the field with a very solid and good quality rock masses where the primary tunnel structure is necessary in the minimum length, D & B method is more economical and cost effective. Under these circumstances, with the application of TBM, advancement is slow and complicated by frequent replacement of the machine head and extremely hard materials [4]. Rocks of the best quality (extremely good and particularly good rocks according to the Q classification) are better suited for Drill & Blast method, especially if

quartz is present in the rocks in a large percentage. Thus, in the application of TBM method, frequent repairs of machinery and replacement of drilling head can occur.
A particular negative effect, when using TBM excavation methods, have dips and caverns. In this case, easily comes to a halt in breaking and jamming of machinery, resulting to waste of "precious" time needed to empower mechanization by using some of the alternative methods (usually D&B). Often, in these zones, incoherent materials appear and fall and clutter machinery for tunnel.
On the graphic - Figure 1 (Barton 2012), the simplest criteria for profitability and selection of one of these methods is clearly presented. It shows the rate of progression of tunnel cutting (m/week) depending on the Q value (Q classification of rocks). TBM method is not suitable for extreme values in Q classification, ie ideal application of this method is in the case of rocks with Q = 1-10 [4].
From this presentation (Nick Barton Hybrid TBM and Drill-and-Blast from start) recommendations are given to use combined method of tunneling by using these two methods where the application of certain stages is clearly and precisely defined.

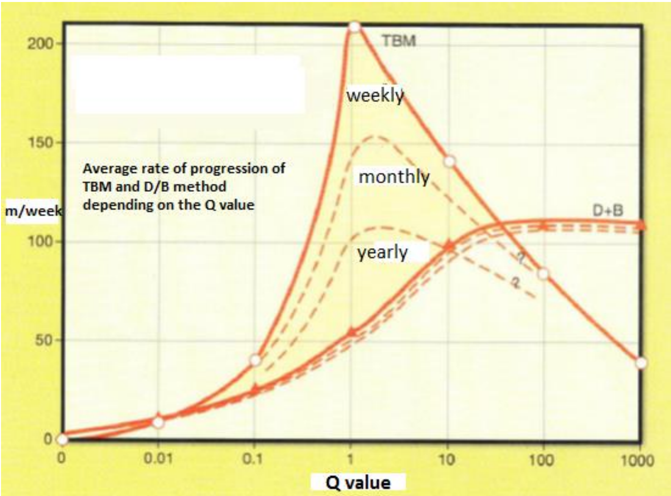

Figure 1 – Rate of progression of tunnel excavation (m/week) using TBM and D&B methods depending on the Q value of the rocks [3]

In addition to the duration of works on the excavation (ie the rate of progression), long tunnels and geo-mechanical characteristics of the rock mass in which the excavation is done, the size of primary structure is also an important factor in making the decision and selection methods. It is generally known that the use of TBM method significantly reduces the size required in the tunnel, but unfortunately the relationship can not be accurately determined because each tunnel is specific and special for itself [5].
The most common use of TBM tunnel excavation method is tunnel for the submission or drainage. These tunnels are usually long with an average diameter of cross-section usually up to 6m. When designing the tunnel for water, route is not strictly defined and determined in terms of the situation, so its relocation and adjustment of the ground is possible. In this

way, the hardest and most unfavorable field conditions and rocks can be avoided and the route, during the design, can be conducted through the most suitable terrain and rocks that can achieve the best conditions for a breakthrough.
Table 2 summarizes the characteristics and comparative analysis of D&B and TBM methods.

Table 2 – The characteristics of D&B and TBM methods

	D&B	**TBM**
Cross section	any shape and any dimensions	constant and limited size
Safety at work	Very dangerous in execution due to the use of explosives and pieces of rock that can fly uncontrollably	Very safe method. When a rock is not a compact, protective covering protects workers on the machine
Costs during operation	High costs during the execution or after the beginning of the excavation	Low costs, but only after the start of work
Investment	Low investment costs. It has a favorable investment costs for tunnels up to 3 km. For longer tunnels profitability is decreasing as the length increases.	High investment costs. Profitability is satisfactory for tunnels longer than 3 km and increasing the length provides higher profitability.
Preparation time for start of the works	Very short period	The long period of mechanization preparation before work start
The principle of execution	Works are repeated cyclically	High-mechanized process
Duration	Very long period until the end	Short period if the terrain is tested in detail and if all conditions are predicted
The surrounding rock material after excavation	Blasting generates numerous large cracks in the rock material around the tunnel	TBM excavation method does not damage the surrounding rock

5. DERIVATION TUNNEL HPP DABAR – METHOD SELECTION

Supply tunnel is part of a derivation system to supply water from the reservoir "Nevesinje" to HPP "Dabar". Diameter of light opening supply tunnel is 4.6 m and its total length is 12095 m. The thickness of concrete structure of the tunnel in open excavation is 30 cm. Based on the performed structural analysis and techno-economic analysis, the solution of

tunnel construction and the entire section (0+000 to 12+095km) is adopted. The conducted stress-strain calculations have clearly shown that the relevant section can be carried out with tunneling or underground excavation [6].
Terrain of wider area, where supply tunnel passes, is built of two sedimentation formations: 1) younger paleogene, in which the developed promina series is built of conglomerate, sandstone, marl and limestone and 2) older Cretaceous, made of limestone with different textures. Morphologically, the terrain has the shape of a plateau and it steeply slopes towards Dabar field in the southern direction, as it is for about 350 meters below the plateau.
Tectonic activity was very high, more disjunctive compared to the plicative. This caused frequent occurrence of the fault structures, among which reverse faults have crucial significance to the geological structure of the field, because the field has the form of overthrust.
On the route of the tunnel, two sections can be generally allocated, according to the geotechnical conditions of the performance of the tunnel. The first is the initial part of the 0+000 to 3+800 km, it is built of the layered to massive conglomerates with layers of sandstone and marl.
Other sections of the 3+800 to 12+125 km is built of layered to massive limestone. On the route of the tunnel there are fault zones and fracture zones that can be karstified and filled with various materials. Fault zones are usually filled with crushed material or clay-filled debris. In addition to the fault zones that may represent very unfavorable environment for the execution of the tunnel, geological conditions for carrying out the tunnel are favorable to very favorable.
Figure 2 shows the percentage distribution of rocks with specific Q value in relation to the total length of the tunnel.

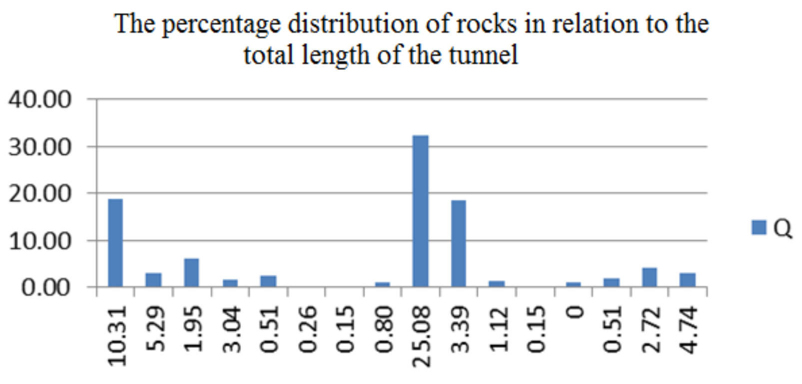

Figure 2 – The percentage distribution of rocks with specific Q value in relation to the total length of the tunnel

Derived division of rock mass on geotechnical mediums is based on all the research works carried out at different times, in this part of the field. In this regard, research data carried out at the site of the dam "Pošćenje" was used, where significantly higher and more diverse research than any research along the route of the water supply tunnel was conducted. Overall, separated geotechnical mediums could be classified into three categories: very

favorable (limestones and conglomerates), favorable to satisfactory (most of the rock mass) and unfavorable to very unfavorable (rock mass from fault zones and clay debris-filled caverns).
Distribution of geotechnical zones is predicted, based on a small number of investigative facilities (9 holes, 11 geoelectric, 10 refractive geophysical profiles and 6 geoelectrical probes) along the route of the water supply tunnel, the results of engineering-geological field mapping (estimation of propagation of important geological structures from the surface to the vertical alignment of the tunnel) and analysis of aero-photo images of the terrain. [7]

The aim of establishing geotechnical model (defining geotechnical mediums) of the rock mass along the tunnel route is to consider all possible engineering-geological-geotechnical conditions that may exist along the route and to make a more accurate prognosis of propagation of geotechnical environments.

6. CONCLUSION

The aim of this paper was to make recommendations and basic guidelines to decide which method to apply for the excavation of the tunnel. TBM method is much faster, but the NATM method is more suitable for tunnels with changing conditions or tunnels where the route passes through the rocks with different physical and mechanical properties. Generally it can be said that the TBM method is more suitable for tunnels larger in length and smaller in diameter and tunnels intended for water flow because the route can be adjusted to the conditions.
Based on this previous works and tests as well as on the information provided about the subject derivation tunnel, view conclusions can be derived, and more guidance in selecting the correct methods of tunneling, which would result in the maximum speed and the advancement of breakthrough of the tunnel and the lowest construction costs.
According to current research and analyzed projects, tunnel HPP "Dabar" is the ideal choice for TBM excavation method (looking in theory), because it is a tunnel length of over 2 km, the tunnel for transport of water from the power plant, it has a regular and constant cross section and smaller diameter along the entire route.
According to these data, it is a tunnel in a relatively favorable environment in terms of physical and mechanical properties of rocks and geological structure of the field, because the rocks have $Q \approx 1$-25 mostly along the whole route.
By analyzing the costs of both alternative solution, it was found that TBM method is more favorable and acceptable.
On the other hand, according to the data given in this article, very few research works have been conducted for this tunnel (only 9 boreholes in the wider area of the tunnel), which means that the data on the ground, rock properties, distribution of cracks, the presence of caverns and fault zones is only approximate and assumed, which is not favourable for the selection of TBM method (as this method requires thoroughly and accurately investigation of the terrain). Thus, in that case, the selection of D&B or excavation method NATM would be better solution.
As a final (optimal) solution for excavation of derivation tunnel HPP Dabar following is proposed:

- Taking into account that this is a water-derivation tunnel, the route of the tunnel is not a fixed and pre-determined, it is necessary to expand the scope of research works as well as terrain-examination in order to obtain the most accurate results.
- Selection of the route of the tunnel, which will pass through the most appropriate material for TBM excavation method with the least fault zones and caverns.
- To begin excavation of the inlet head and prosper downstream.
- At the same time, to begin excavation of the access tunnel and the main tunnel to the exit of the head upriver, using NATM method, to join the main route.

It is clear, from the above mentioned, that any tunnel is specific, so one method can not be generally favored, hence it is necessary, for each individual facility (tunnel), to identify and analyze all incoming data and circumstances and make the final decision (optimal solution) by adequate numerical indicators (values), which can be easily compared.

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АНАЛИЗА УСЛОВА ГРАЂЕЊА ДЕРИВАЦИОНОГ ТУНЕЛА У ХЕРЦЕГОВИНИ

Резиме: *Тунели су специфични објекти који се граде испод површине терена, у циљу савлађивања неких препрека и могу се сврстати у најсложеније инжењерске објекте за саобраћај и транспорт, спајајући две целине раздвојене препреком. Предмет рада је анализа и поређење метода ископа тунела за потребе хидроелектране "Дабар" у Невесињу. Анализа је базирана на пројектно-техничкој* *документацији деривационог тунела као и досадашњим теоријским и практичним истраживањима и радовима. Циљ рада је да се проучавањем и анализом више различитих метода ископа тунела (НАТМ, ТБМ метода) и упоређивањем њихових карактеристика предложи оптимална метода ископа за конкретан објекат. На основу анализе услова грађења (карактеристика локације), сагледано је и теоретски предложено најповољније решење и комбинација решења, ископа деривационог тунела за потребе хидроелектране.*

Кључне речи: *Тунел, метода, ископ, решење, анализа*