SELECTION OF CONSTRUCTION METHODS IN ROCK TUNNELING

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Abstract

For construction of long infrastructure tunnels in rock the use of tunnel boring machines (TBM) could be an economical and fast construction/excavation method. However, a careful preliminary evaluation of construction costs, construction time and technical feasibility (i.e. geotechnical risks, TBM-requirements and type of TBM) shall be carried out in an early stage. Normally, the construction/excavation method should be already determined for environmental impact assessment and building permission procedures. In the presentation the selection of adequate construction methods for the 27.3 km long Semmering Base Tunnel will be shown.

Keywords: long infrastructure tunnel, use of TBM, geotechnical risk assessment

1 INTRODUCTION

For the design and construction of long railway and road tunnels in rock a thorough study and comparison has to be carried out with respect to the construction method to be used. Many factors have an influence on choosing a technical feasible and economical construction method. So it could be often difficult to decide finally in the design process which construction method, TBM or NATM, is technologically and economically more advantageous. For the economic comparison of both methods the designer will carry out a cost estimate mainly based on reference projects. Several parameters which have an influence on the bidding price such as market situation, availability of used TBM or personal resources cannot be considered in the designer´s cost comparison.

2 FACTORS OF INFLUENCE

For selecting a technically feasible and also economical construction method there are several aspects to be taken into consideration. The main factors are briefly described below. For deciding the best construction method many of these factors described have to be taken into account in combination.

2.1 TUNNEL LENGTH

Even there is no sharp limit on the tunnel length NATM normally has an economic advantage for shorter tunnels. For transportation tunnels in rock longer than 4 to 5 km a TBM drive might be considered from the economic point of view.

2.2 TUNNEL CROSS SECTION

For longer railway tunnels normally two parallel single track tubes are required from maintenance and safety point of view during later operation. Longer double track tunnels would require vertical escape shafts (e.g. Lainzer Tunnel) or horizontal emergency exits to the surface at 500 m spacing. In mountainous areas with high overburden (e.g. Semmering Base Tunnel or Koralm Tunnel) parallel single track tubes are therefore the only possible solution.

Long road tunnels have the necessity of a considerable number of niches (e.g. emergency call niches, firefighting niches, parking bay niches) where for construction of the niches the segmental lining of a TBM tunnel has to be opened or partially removed. In circular shaped profile of TBM tunnels the large space below the carriageway might be used for accommodating ventilation ducts, escape routes and electro-mechanical facilities.

Beside the required minimum clearance profile the selected construction method will have an impact on the size of excavation cross section. Using NATM the shape of the profile can be adapted to the clearance profil and space needed for installations (e.g. tunnel ventilation, cable ducts, drainage pipes etc.). In TBM tunneling the excavation profile is circular shaped and therefore larger compared to NATM tunneling.

2.3 GEOLOGICAL, HYDRO-GEOLOGICAL AND GEOTECHNICAL CONDITIONS

In general, geological; hydrogeological and geotechnical conditions are one of the decisive factors for selecting the construction method. NATM is a very flexible method with respect to excavation (drill&blast or mechanical excavation), means of rock support, face support and required auxiliary measures. Excavation sequences, enlargement of excavation profiles for allowing displacement of the surround rock mass, subdivision of headings, amount and means of rock support can be adapted rather easily and quick to the actual ground conditions encountered. Additional measures built in at the heading face (e.g. grouting, dewatering, installation of pipe roof umbrellas, shotcrete lining with yielding elements) can cope with adverse conditions in fault zones.

In TBM tunneling possible installation of additional measures at or above the cutter head is limited due to space constraint. In addition unexpected fault zones or very unfavorable rock mass behavior can cause considerable disruptions to the intended continuous drive, or even stoppages and longer interruptions. However nowadays modern TBMs can be designed to cope with a wider range of rock conditions. Dual mode TBM`s can be operated alternatively with face support by the cutter wheel or with an active face support (e.g. as an EPB – TBM) in case of unstable conditions in front or above the cutter head. In severely squeezing rock conditions (e.g. in extended fault zones with higher overburden) radial displacements of the excavated rock mass have to be allowed in order to minimize rock pressure on the shield skin and segmental lining. The adaption of the excavation diameter and allowance for radial displacement is possible to a certain degree by the so-called copy-cutter-technology. TBMs with radially yielding telescopic shield skins have not yet been tried in practice.

In course of the geotechnical design the technical and economic feasibility of adequate construction methods have to be evaluated by a risk analysis. The risk analysis for possible construction methods serves to identify scenarios (events) to be considered in the geotechnical design and forms the basis for selecting an adequate construction method.

Basis for assessing the interaction between the tunnel structure and the surrounding rock mass are the geological and hydrogeological projections as well as the geotechnical design. Risks resulting from projection uncertainties are normally not incorporated in the risk analysis per se, but have to be taken into consideration by applying a separate risk surcharge for unforeseen conditions in the estimate of construction costs and time. The risk assessment should be supported by using analytic and numerical analyses for identifying the rock mass behavior and to estimate or verify the system behavior (interaction of rock mass behavior and tunneling requirements). For the risk assessment of using a TBM special attention has to be paid to the interaction between the encountered rock mass and the operating machine.

The identified risk scenarios are evaluated using a "risk matrix" by multiplying the "degree of damage" A(i) and the "occurance probability" W(i):

$$R(i) = A(i) \times W(i). \tag{1}$$

The different steps of the risk analysis are shown in Fig. 1 below.

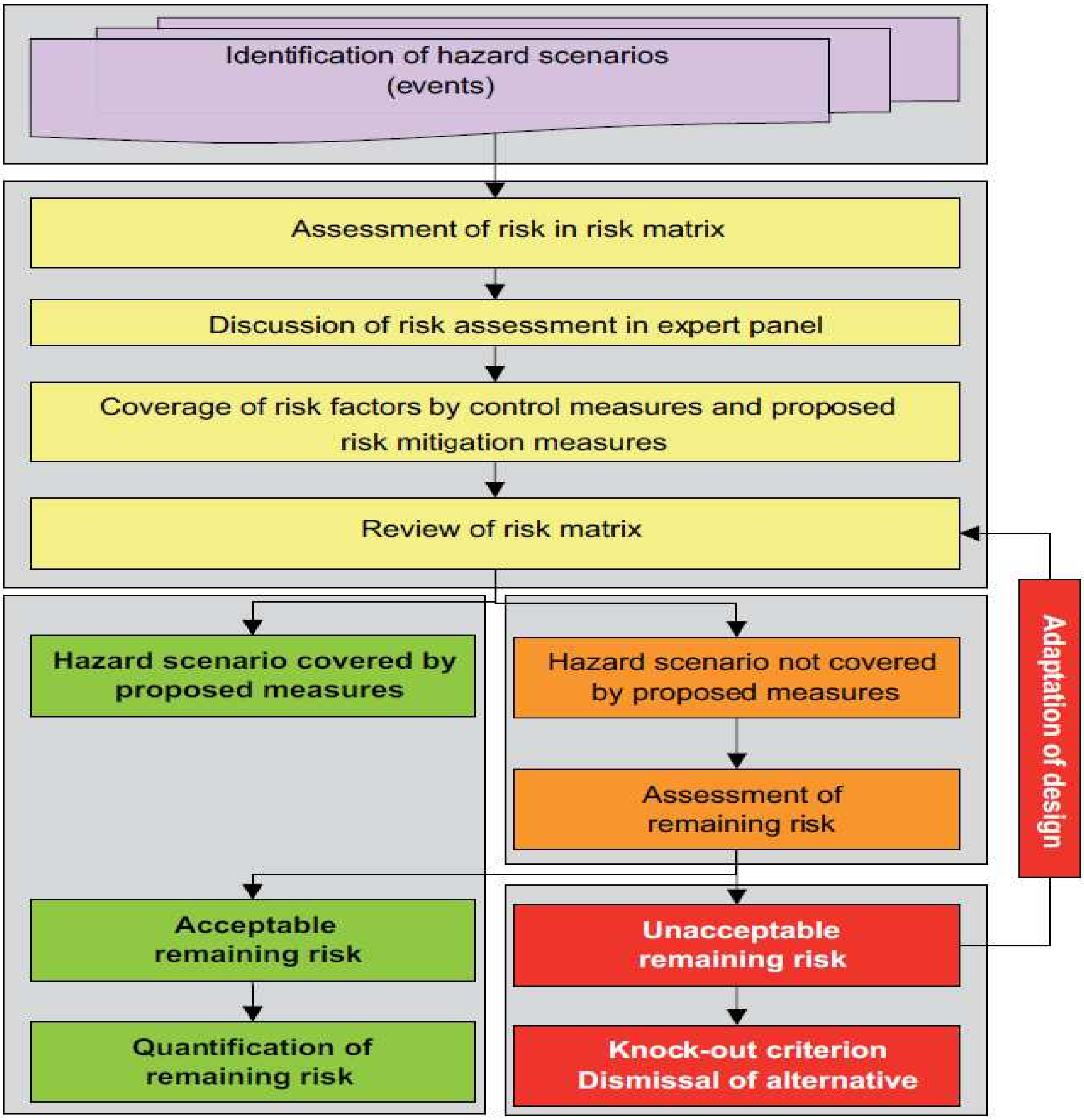

Fig. 1: Flow diagramm – steps of risk analysis

The fundamental evaluation criteria established for each risk (hazard) scenario (event) should be checked and discussed by an expert panel. In a next step it has to be checked which of the identified risks can be covered by design measures or additional measures for mitigating the risks. Such risk scenarios are not considered in further evaluations.

Risks which cannot be covered by additional design measures are identified as “remaining risk”. The remaining risks are further assessed und either regarded as “acceptable remaining risks” or “unacceptable remaining risks”. If unacceptable remaining risks cannot be eliminated by further reassessment (e.g. adjustment of tunnel alignment) they are regarded as knock-out criteria and lead to elimination of the respective construction method.

For estimating construction costs and comparison of different construction methods acceptable remaining risks have to be quantified.

2.4 TUNNEL LINING

In Austria road and railway tunnels applying NATM are normally constructed with a double layer lining consisting of the outer (primary) lining and inner (secondary) lining. In most of the projects a waterproofing membrane is placed between outer and inner lining. Whenever possible from the environmental point of view, groundwater pressure onto the tunnel lining is avoided or at least limited by installing longitudinal sidewall drainage pipes.

TBM tunnels could be designed with either a single or double layer lining. Depending on the expected height of groundwater pressure onto the lining the tunnels can be also drained similar to NATM tunnels.

In the heterogeneous geological and geotechnical conditions prevailing in the Alps the use of “open type TBMs” (TBM-O) is not feasible for transportation tunnels with large cross sections. Therefore either single shield TBMs (TBM-S) or “double shield TBMs (TBM-DS) are used. Using shielded TBMs precast segments are applied to support the excavated rock behind the shield. For sections with a double lining system an in-situ placed inner concrete lining is installed later on. In this case compared to a single shell lining the requirements (e.g. accuracy of producing and placing the segments, joint details, sealing of joints) on the segmental lining can be lower (e.g. “Swiss segments” used at the Wienerwald Tunnel).

In Semmering tunnel a double lining system with longitudinal sidewall drainages will be applied for the entire tunnel length independent from the tunneling method selected (see Fig. 2).

2.5 CONSTRUCTION LOGISTIC

For construction of long transportation tunnels the project has to be subdivided into several construction lots in order to achieve an acceptable construction time. However, each construction lot needs at least one separate construction access with sufficient space for all the needed site installations. For example, the 27.3 km long Semmering Base Tunnel was subdivided into three main construction lots for mined tunneling. There are one tunnel portal in Gloggnitz and three intermediate construction accesses by two vertical shafts each.

Beside the required site installation areas high capacity access roads for supplying the needed construction material and dumping the excavated rock have to available.

Requirements for construction logistics will depend on the different construction methods investigated.

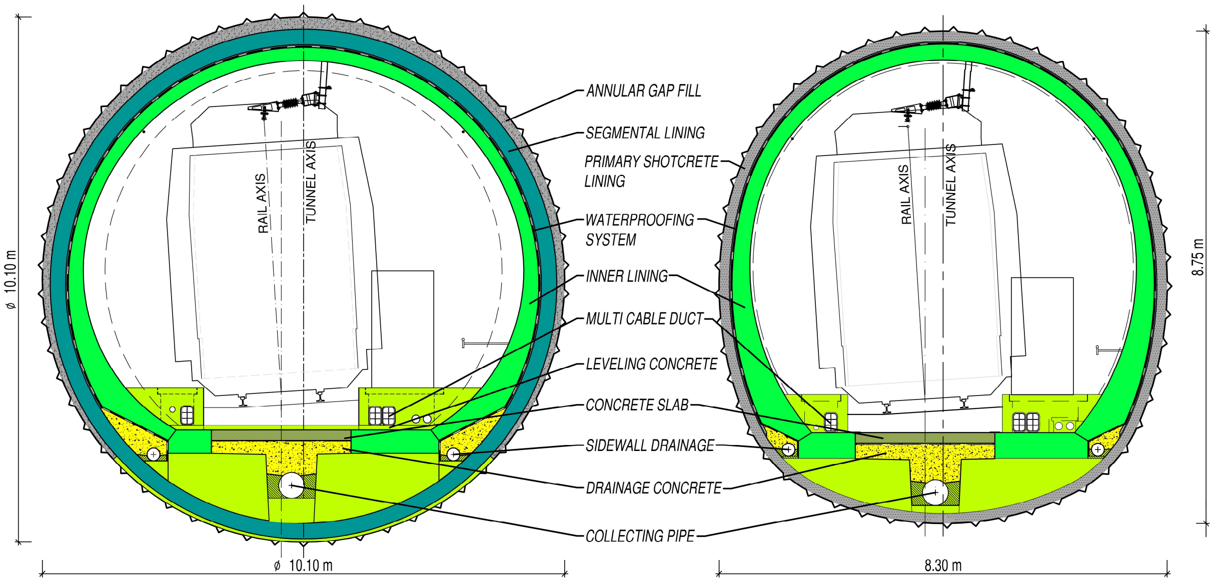

Fig. 2: Tunnel Cross Sections for TBM-drive and NATM-heading at Semmering Base Tunnel

2.6 ENVIRONMENTAL ASPECTS

Especially transportation by trucks, construction noise from the site installation area, illumination at the site area at night and propagation of dust has to be considered from the environment impact of view. If feasible the excavation material should be used as construction material at the site (e.g. aggregates for shotcrete and concrete or for embankments). The exaction method (drill&blast or mechanical excavation by TBM) could have an influence on the reuse of the excavated rock mass.

Muck disposal sites should be found near the project area or should be deposited by rail. For shorter distances conveyer belts are an alternative.

Special attention has to be paid to the treatment and discharge system of ground/mountain water encountered during tunneling.

For tunnels with shallow cover underneath built-up areas noise, vibrations and settlements could be affected by each construction method in a different way.

2.7 HEALTH AND SAFETY

For occupational health and safety during construction TBM tunneling provides an advantage over the NATM. In particular shielded TBMs with segmental lining ensure a higher safety for the miners. The crew is always working in the protection of the TBM shield or the installed segmental lining.

Ventilation requirements could be different for each of the construction methods. In general more fresh air has to be supplied to the headings by using NATM. For longer NATM drives additional ventilation shafts during construction could be necessary.

2.8 CONSTRUCTION TIME

Construction time and completion of a project is crucial for each infrastructure project with long tunnels. Therefore the estimated construction time is an important factor in the selection of the construction scheme (number of construction lots, intermediate construction accesses) and construction method (excavation method, lining system).

In NATM tunneling average daily advance rates can reach 10 to 15 m in favorable rock conditions with peak rates up to 20 m/day. Even in poor conditions (e.g. in fault zones) 2 to 3 m/d are possible due to the high flexibility of the method.

Basically by using a TBM much higher daily advance rate can be achieved in good to moderate geotechnical conditions. Average daily advance rates of more than 20 m/d are often possible with peak rate around 40 m/d. But there is a higher danger that TBM driving has to be stopped temporarily in poor geological conditions resulting in additional construction time. In addition it takes about 12 – 15 months to order, design, manufacture, transport and assemble a new TBM at the site. This duration can be very disadvantageous if only a few months preparatory works is required before starting tunneling. By applying a single shell ling the construction time can be considerably shortened.

When applying NATM tunnel excavation can normally be started after 3 – 4 month time needed for mobilization, site installation and portal excavation. But due to lower progress rates compared to a TBM drive NATM tunneling could result in a longer overall construction time or additional intermediate construction accesses (e.g. vertical shafts, horizontal or inclined access galleries) are necessary.

2.8 COST COMPARISON

If both construction methods NATM and TBM tunneling are technically feasible the cost comparison can be the decisive factor. In the cost estimate for each construction method not only the construction costs are considered but also quantified accepted remaining risks, a surcharge for unforeseen conditions and differences in operation and maintenance costs.

3 SELECTION OF CONSTRUCTION METHODS AT SEMMERING BASE TUNNEL

3.1 INTRODUCTION OF THE PROJECT

The approx. 27.3 km long Semmering Base Tunnel will link the railway stations at Gloggnitz and Mürzzuschlag as part of the Baltic-Adriatic axis running from the Gdansk to Bologna. After commissioning of the project in early 2005, the present alignment was chosen as the best route of altogether 13 possible variants in the next years. Geologic and hydro-geologic conditions were then investigated in more detail and led to an optimised alignment in a further two years of design work.

The results of these investigations formed the basis for environment impact assessment and design for building permission. These documents were handed in for approval in May 2010 to the Federal Environment Ministry and the Railway Supervisory Office. Parallel to the approval phase a study has been carried out for selecting adequate construction methods along the entire alignment. The result of this evaluation was the bases for subdividing the project into design and construction lots, selection of excavation methods in each lot and finally preparing tender documents for construction works.

The Semmering Base Tunnel consists of two parallel single-track bores with cross-passages at a maximum spacing of 500 m. For reasons of construction access, construction logistics, acceptable construction time and topography, altogether five starting points for tunnel construction were decided.

There is the portal in Gloggnitz, three intermediate starting points (Göstritz, Fröschnitzgraben and Grautschenhof), which enables the tunnel to be driven in three main construction lots, and one short cut&cover section at the western end in Mürzzuschlag (see Fig. 3). After completion emergency stop facilities will be situated in the central section (Fröschnitzgraben) with 2 shafts about 420 m deep being used for ventilation in case of an emergency.

The project is located in a geologically complex part of the Eastern Alps. Several geological units are encountered in the project area. The rock mass includes numerous different rock types with a wide range of geotechnical and hydrogeological properties.

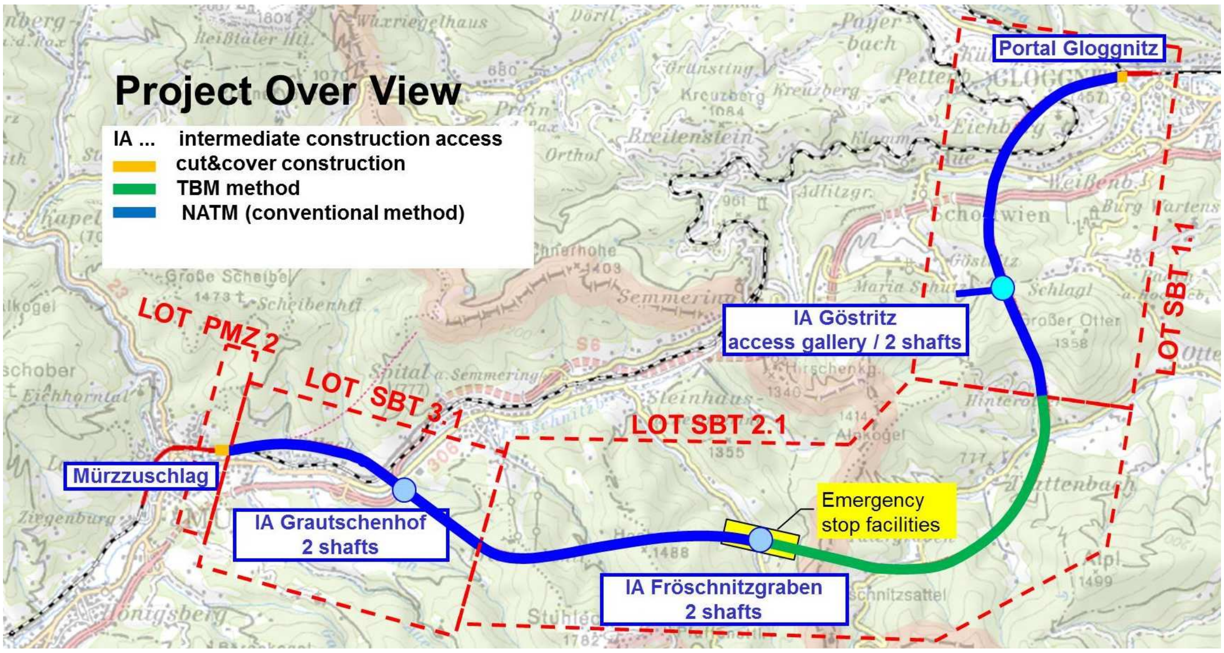

Fig. 3: Project layout

3.2 GEOTECHNICAL DESIGN AND RISK ANALYSIS

In accordance with [6] and [7] so-called “rock mass behavior types” (ground behavior) were defined in a first design step by numerical and analytical calculations based on the results of a detailed investigation program. The “rock mass behavior types” were allocated to tunnel section with different rock mass types and corresponding overburden. Considering those results based on geological, hydrogeological and geotechnical prognoses risk analyses was carried out for both tunneling methods.

The identified risk scenarios (events) were divided into following four groups:

1. Interaction between tunnel heading and rock mass
2. Tunneling equipment
3. Inner lining, dewatering and drainage system
4. Environmental aspects

Group 1 is the most important from the geotechnical point of view. Especially for the TBM-method the interaction between the encountered rock mass and the selected TBM has a mayor influence on the technical feasibility.

Group 2 mainly contains events which are in the responsibility of the later contractor. The impact of such risks on using NATM is minor. For TBM tunneling a detailed description of the ground close to its real behavior is required to specify and choose the right type of machine as well as to minimize risks in connection with the TBM used.

Group 3 deals with risks in connection with the design of inner lining, dewatering and drainage system. In this aspect also the effect on later maintenance work has to be considered.

Group 4 covers risk scenario which might have an environmental impact such as transportation, noise, dust, vibrations, surface settlements and re-use of muck material.

3.3 CONCLUSION

The risk analysis proved that NATM tunnelling can cope with all the events identified for this method by utilizing additional measures as specified in the geotechnical design.

Since the risk analysis for TBM tunnelling yielded in unacceptable remaining risks (knock-out criteria) for several sections along the tunnel alignment. Such areas were identified mainly in extended fault zones with expected high radial displacements. In such sections there is a very high risk that the TBM-drive comes to longer stoppages and clogging of the machine.

TBM tunnelling on a longer stretch was found feasible only for the 8 km long eastern drive of construction lot SBT2.1. In the tender documents the bidders could offer either a single shield TBM (TBM-S) or a double shield TBM (TBM-DS). The winning contractor chose the first option.

For the entire project a double shell lining with longitudinal sidewall drainage pipes was designed.

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