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Semmering Base Tunnel – Challengies in predicting rock mass quality in a major fault system

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Abstract

The Semmering Base Tunnel (SBT) with its total length of 27.3 km comprises many geotechnical challenges including the crossing of the more than 1 km long Grassberg-Schlagl fault system consisting of a wide range of heavily sheared lithologies with varying geotechnical properties. The geological model of the design stage covers the needs of the support concept, but more detailed information are required to ensure safe and efficient tunnelling. The prediction of the geological conditions is essential for getting the indications for a modification of the excavation concept on time Therefore an extensive programme of exploratory drillings was part of the tender design.

The first choice for obtaining information about the in-situ conditions of a rock mass are core drillings. However, horizontal core drillings didn´t reach the desired length due to plastic deformation and water sensitivity of parts of the fault material. Consequently, the exploration method changed to overburden drillings without core recovery to provide a stable borehole. For the geologist it is hard to estimate the rock mass properties just from the fine-grained cuttings. Therefore, a combination of exploratory methods such as mineralogical analyses, geophysical borehole logs, drilling data and physical measurements are used to extract the principal data for the geotechnical engineer from a wide range of oblique information. Especially testing the solubility of the cuttings did a good job to estimate the degree of a secondary cementation of the cataclasite by sulphatic minerals, which was essential to distinguish zones of poor rock mass quality from more competent areas.

The article describes the efforts in establishing exploratory drillings in the construction process and gives an overview over the methods used for updating the geological forecast. Finally, a comparison between the geological model and the conditions encountered during excavation evaluates the success of exploration.

Keywords

fault zone, geological forecast, rock mass quality, sulphate minerals, Semming Base Tunnel

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1 Project Description

The Semmering Base Tunnel (SBT), which is approx. 27.3 km long, lies in Eastern Austria and forms part of the Baltic-Adriatic Corridor. The two single-track tunnels between the Gloggnitz and Mürzzuschlag portals are the main components of this tunnel system.

The SBT1.1 “Tunnel Gloggnitz” section is the most easterly of the three construction lots. Construction of this lot began in 2015 using conventional tunnelling methods. This lot involves the construction of the two main tunnels which are being excavated from the Gloggnitz portal. The two main tunnels are also being driven from either side of the Göstritz intermediate access point towards Gloggnitz and Mürzzuschlag. The tunnels in lot SBT1.1 have a total length of approx. 7.3 km and are linked by 16 cross passages.

The tunnel section described in this article has a total extent of 1.4 km. It has been driven from the intermediate access Göstritz north in direction of the Gloggnitz portal.

2 Geology

The tunnel section is confronted with many geotechnical challenges. Over a length of almost 6 km, the tunnel crosses several tectonic units, which are intensively imbricated and sheared by large lateral shifts. Those intensive tectonic processes resulted in highly heterogenic geological conditions with small-scale lithologic changes and widely varying rock quality, as well as a generally high proportion of fault rocks and tectonically intensively stressed rock sections.

More than ¾ of the excavated rock mass was heavily sheared or faulted. The rock mass section described in this article is part of "Grassberg-Schlagl fault system", one of the largest tectonic lineaments on the eastern margin of the Alps with active seismicity. The total thickness is approximately 2km, which is twice as much as the assumed prior to project execution. Lithologically, a predominantly silicate area in the north can be differentiated from a predominantly carbonate area in the south (see Fig. 1).

The rock mass can be described as a “tectonic melange” or as a BiM-rock (block-in-matrix). Characteristic is the small-scale change of the different lithologies, whose strength is mainly reduced by the intensive tectonics. The matrix consists of mostly greenish sericite phyllites, which occur as cataclasites with partial properties of plastic soft rock but with a relict schistosity and thus a geomechanically effective anisotropy This matrix contains sheared strata and shear bodies of quartzites, brecciated dolomites, dark limestones alternating with slates as well as sulphatic rock bodies that occur in the form of gypsum breccias and, locally, anhydrites. The dimensions of the shear bodies vary greatly ranging from block sizes to 10-metre-thick layer structures. Quartzites occur on the one hand as a low-anisotropic, softened grit with relict fracture bodies, and on the other hand as competent, moderately anisotropic shear bodies with sometimes high strength. Carbonates mostly form competent bodies within the faulted rock mass.

The phyllitic fault matrix is often sulphate-cemented, especially in the vicinity of the gypsum breccias, resulting in significantly higher rock strengths of the cataclasite areas than formerly. This has a positive impact on system behaviour. In the north of the fault system, however, this secondary consolidation subsides within a short distance, which led to extremely challenging geotechnical conditions over an extension of about 600m. Moreover, the rock mass on the northernmost 400m consists of rather homogeneous fault rocks of a mica schist with almost no competent components. This challenging section reaches almost three times the extent of the geological forecast.

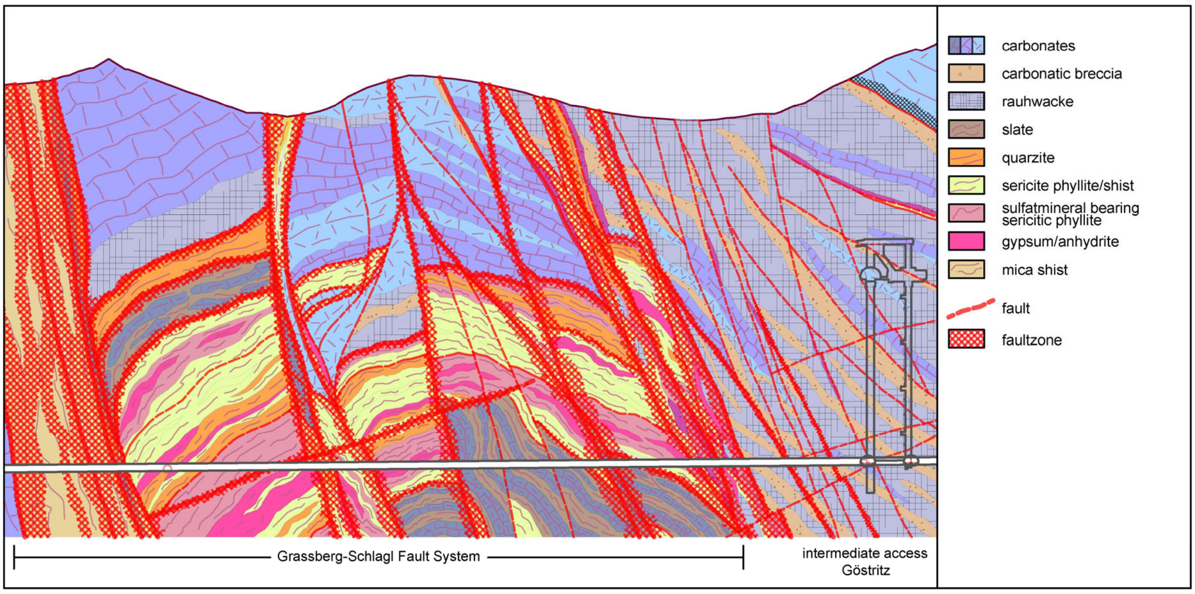

Fig. 1: Figures must be referred to in the text. Try to place the figures close to were they are referred to in the text [ÖBB 2014].

3 Determining rock mass quality in fault material

Determining the geotechnical parameters of a faulted rock mass is crucial for designing the structural safety of a tunnel. Though, it´s exactly this kind of rock mass, which is hard to be described by numerical values. Undisturbed samples of fault material are needed to obtain reliable estimations of relevant geotechnical parameters. Scarce outcrops in the field are not a significantly valuable source of information, as the exposed rock is likely to be weathered with strongly altered geotechnical parameters that are simply not comparable to the unaltered rock mass in the depth of the tunnel. In the stage of the tender design core drillings are the only way to get rock samples from the material of interest. It is common sense among geologists and geotechnical engineers that a drill core represents the in-situ conditions of the rock mass. This opinion seems not to be true in the case of some fault materials in the project area.

The fault material of the Grassberg-Schlagl fault system derived from schists and phyllites. Hence, cataclasites are of fine-grained composition and tend to disintegrate under the influence of water. Reaching the tunnel depth required core drillings of more than 500m length, which turned out to be a challenging task just to reach the target area, as the prevalent squeezing conditions caused frequent collapses of the borehole. Recovering core samples of good quality was even more demanding. Double core barrels with liner were used, but they are difficult to apply in greater depths. Once opened the liner core sample reacted quickly with a gain in volume because of decompression.

Despite the extensive drilling programme in the Grassberg-Schlagl fault system only a few samples were available for rock mechanics investigations on fault material (see Fig. 2) to prove the feasibility of the project. Regarding geotechnical parameters a conservative approach had been made finding a compromise between the required tunnel safety and still economic feasibility.

Fig. 2: Rock mechanics investigations on fault material.

4 Exploratory drilling plan

To minimise the risks of tunnelling, it is particularly important to understand and assess the rock mass and groundwater conditions and their possible impacts on tunnelling at a sufficient distance ahead from the tunnel face. To clear up remaining uncertainties of the geological model to assess the geotechnical risks in this major fault zone another extensive exploration program was planned to be executed during the construction project. The programme consisted of exploratory drillings (with or without core recovery), open-hole geophysics and hydraulic testing.

4.1 Exploration target

The squeezing rock mass of the Grassberg-Schlagl fault system provided ongoing challenges for the geotechnical engineer to choose the appropriate tunnelling and support concept. The dimension and the strength of rock bodies within the fault matrix as well as the degree of sulphatic cementation of the matrix itself have a major impact on the rock mass quality. Although there is no way to determine geotechnical parameters a qualitative prediction must be undertaken to plan ahead. Having at least a reasonable estimation of expected deformations is crucial for planning ahead concerning e.g. the appropriate number of yielding elements, dimensioning the excess excavation as far as the need for partial excavation or a pilot tunnel.

In another part of the construction lot SBT 1.1 a massive overbreak occurred following the erosion of fault material adjacent to an aquifer of limited extent. The carbonate rocks of the Grassberg-Schlagl fault system were assumed to bear small but eventually highly pressurized water bodies. Overlapping exploratory drillings within the fault zone were essential to minimize the geotechnical risk of an uncontrolled water inflow eroding the cataclasite.

4.2 Horizontal core drillings in fault zones

An appropriate estimation of the rock mass parameters of fault material requires undisturbed core samples. Already difficult in vertical drill holes, this task becomes increasingly challenging in horizontal drillings. Executing these boreholes into fault rocks poses inherent challenges in drilling. Consequently, drilling problems increasingly arose out of approaching the Thalhof-Aue Fault Zone, another major fault zone in lot SBT 1.1. As the boreholes were driven into the core of the fault zone, it became impossible to achieve the planned final depths of > 100 m. As soon as the drilling path was located in plastic fault rocks, some of the drillings had to be aborted after just a few meters. The flushing led to a deterioration in the consistency of the fine-grained fault rock compared with its in situ condition. This resulted in increased skin friction, impeding the return flushing and ultimately jamming the entire drill string. Even after numerous technical modifications, a final depth of only approx. 20 to 30 m was achieved.

It became obvious, that the original exploratory drilling plan must be adapted to avoid an increased geotechnical risk.

4.3 Alternative drilling concept

In vertical drillings an adaption of the flush medium is the preferred method to stabilise boreholes. This effect is limited drilling horizontally, as the fluid constantly comes out of the borehole while drilling. An alternative drilling concept had to cope with this problem. The main requirement was a stabilisation of the borehole while drilling. Additionally, the drilling rig should provide enough force to prevent the drill rods of becoming jammed into the fault material. Overburden drillings were expected to fulfill all the requirements.

Overburden drill rods consist of a casing (outer pipe) and drill pipes (inner pipe), which are driven simultaneously into the borehole. The casing provides an instant stabilisation of the borehole. The flushing medium is pressed through the drill pipes and is forced back out again at the mouth of the borehole or at the discharge head, along with the loosened drill cuttings, through the annular gap between the drill pipes and the casing. The system enabled the desired exploratory lengths, however it could only be used as a destructive method without core recovery.

Before starting tunnelling in the Grassberg-Schlagl fault system it could be proofed that with overburden drillings, target depths of 120-150m can be achieved even under difficult geological conditions. All boreholes were drilled with standpipes and blow-out preventers.

5 Updating the geological model

5.1 Requirements to the geological forecast

The use of destructive exploratory drilling meant that a great deal of information for assessing the structure and expected rock behavior, which could normally be obtained from core drillings, was not available to the geologists. However, the main exploration targets didn´t change, and a geological forecast as precise a possible was still essential for safe tunnelling. Along with the change of the drilling method the geologists had to adapt their methodology to obtain the desired information. Naturally, the direct gain in reliable data on rock and rock mass is significantly lower in a destructive borehole and the proportion of interpretations in the statements is higher than in a borehole with satisfactory core recovery. However, the addition of borehole geophysics can help to reduce the uncertainties. The systematic use of overburden drillings in the Grassberg-Schlagl fault system represents a compromise between the required drilling lengths and the exploration objectives.

Using this exploration method (including borehole geophysics), the following statements should be possible:

- Differentiation between faulted and intact rock mass sections
- Identification of anhydrite or suspected areas
- Ground water conditions

The update of the geological model had to be done in a truly brief period of time in order to enable decisions about further measures without interrupting the tunnelling.

To fulfill the requirements for the geological forecast the following information was available:

- Assessment of cuttings (including mineralogical analysis)
- Geophysical logs and – if necessary - hydraulic testing
- Drilling data
- Electrical conductivity

The individual methods are explained in more detail below.

5.2 Assessment of cuttings

A good lithological profile along the drill path is essential for further assessment of geotechnical properties of the rock mass. Sampling of the cuttings was carried out at intervals of 1.5 m according to the length of the pipe sections. Each sample is packed into a plastic bag, which makes handling during the documentation process easier. In the present rock mass, the overburden drilling usually produces very fine-grained cuttings (see Fig. 3), which makes lithological identification difficult. The use of a microscope facilitates identification, but it is a time-consuming process. So, the assessment of the cuttings requires experienced geologists, who know the properties of the individual rocks from face mapping. Mineralogical analysis (XRD) help to clear up remaining questions. In cases of urgency, the results were available within 24 hours.

Fig. 3: Difficult assessment of fine-grained cuttings.

5.3 Geophysical logs

The exploration concept of the tender design provided a vast variety of geophysical logs, such as borehole camera (CAM), optical/acoustic borehole imager (OBI/ABI), full-wave-sonic (FWS), natural gamma ray (NGR) and drill path deviation (DEV). The combination of these methods would give a perfect overview of the in-situ condition of the rock mass provided that the data are complete for the whole drill path. Unfortunately, only a small part of this information could be obtained in the Grassberg-Schlagl fault system. Large parts of the boreholes were unstable so that open hole logging was hardly possible. Only NGR and DEV can be logged in cased boreholes and deliver almost complete data sets. The NGR helps to precise the lithological profile derived from the cuttings. Mica bearing schists and phyllites can be easily distinguished from quartzite, carbonates, or sulphatic rocks. It doesn´t give any information about the rock mass quality and the structures.

5.4 Drilling data

The drilling rig had the possibility to record the following data:

- Advance rate
- Downforce pressure
- Torque
- Flushing pressure

Additionally, the notes and comments of the drilling operator about the strength of the rock mass were also available for the geologist's interpretation.

Drilling data give a rough indication of the occurrence of competent rock bodies within the fault zone. Jointed and brittle rock mass sections can be distinguished from the soft fault matrix. Further differentiations are hardly possible. The plastic deformation of fault rocks results in an increase in torque with increasing depth, which makes interpretation of the drilling data more difficult.

5.5 Conclusions and further investigations - electrical conductivity

The methods described in the chapters above do not offer any possibility to estimate the rock mass quality of the phyllitic fault matrix. Observations during the excavation works of the access tunnel Göstritz in the same geological formation, 3 years before tunnelling through the Grassberg-Schlagl fault system with the main tubes, proofed that the degree of sulphatic cementation of the cataclasite (sericitic phyllite) is a key factor for the rock mass strength of the fault matrix. However, the methods mentioned above are not sufficient for the estimation of the degree of cementation. Parts of the gypsum content are dissolved by the drilling fluid. The remaining parts do not change the appearance of the phyllite-dominated cuttings very much, as the gypsum fragments are difficult to detect even with a microscope. XRD-analyses often revealed only traces of gypsum. It became obvious that even lesser amounts of gypsum have a significant effect on the rock mass quality. These low contents of gypsum do not have much influence on the gamma logs either as the peaks are caused by the occurrence of phyllosilicates. Only higher amounts of sulphate minerals cause a drop of the gamma values, but these could also be attributed to the presence of carbonates or quartzites.

To improve the quality of the geological model, another method had to be found to recognize the low sulphate content. We used the physical property of gypsum and anhydrite to dissolve in water easily. One tablespoon of cuttings in 200ml of fresh water causes a quick increase in the electrical conductivity if sulphate minerals are present. Accurate measurement requires a constant temperature of the solution in all samples. Doing this for each sample along the drilling path creates a complete log of the solubility of the cuttings. Plotted in comparison with the gamma log provides a good indication of the lithological sequence and the geotechnical properties. A high value of the electrical conductivity coinciding with a high gamma can be interpreted as a sulphatic cemented fault matrix, whereas coinciding with a low gamma is an indication for massive bodies of gypsum or anhydrite. A low electrical conductivity occurring together with a high gamma refers to a lack of cementation and a poor rock mass quality, whereas a low electrical conductivity with low gamma points to in our case competent carbonate or quarzitic shear bodies.

6 Evaluation of results

The exploration methods described above did not offer a direct view into the rock mass ahead. Rather, they were soft facts with a high degree of interpretation. However, tunnelling through the Grassberg-Schlagl fault system after each exploratory phase showed, that the methodology worked well under these particular circumstances. Despite the extraordinarily complex structure of the fault system the geological-geotechnical conditions ahead could be predicted very precisely. The degree of sulphatic cementation, which turned out to be a key factor to assess the rock mass as favourable or unfavourable, could be anticipated successfully. The combination of methods made it possible to reveal the geotechnically important characteristics of the rock mass. The conductivity log can be generated very easily and quickly without additional costs. The same applies to drilling data. Carrying out geophysical logs in the cased borehole proved to be another very important source of information, even if open hole logging was only possible to a very limited extent.

As show in Fig. 4 crown displacements confirmed the accuracy of the geological model. Competent rock mass sections could be distinguished from areas with geotechnically challenging conditions. After a first evaluation project participants gained confidence in the methodology. This gave us the opportunity to act proactively instead of just reacting. Appropriate decisions about tunnelling concept and support could be made or at least prepared in an adequate distance to changing rock mass conditions. Consequently, the methodology made a major contribution to safe and efficient tunnelling under exceedingly difficult circumstances.

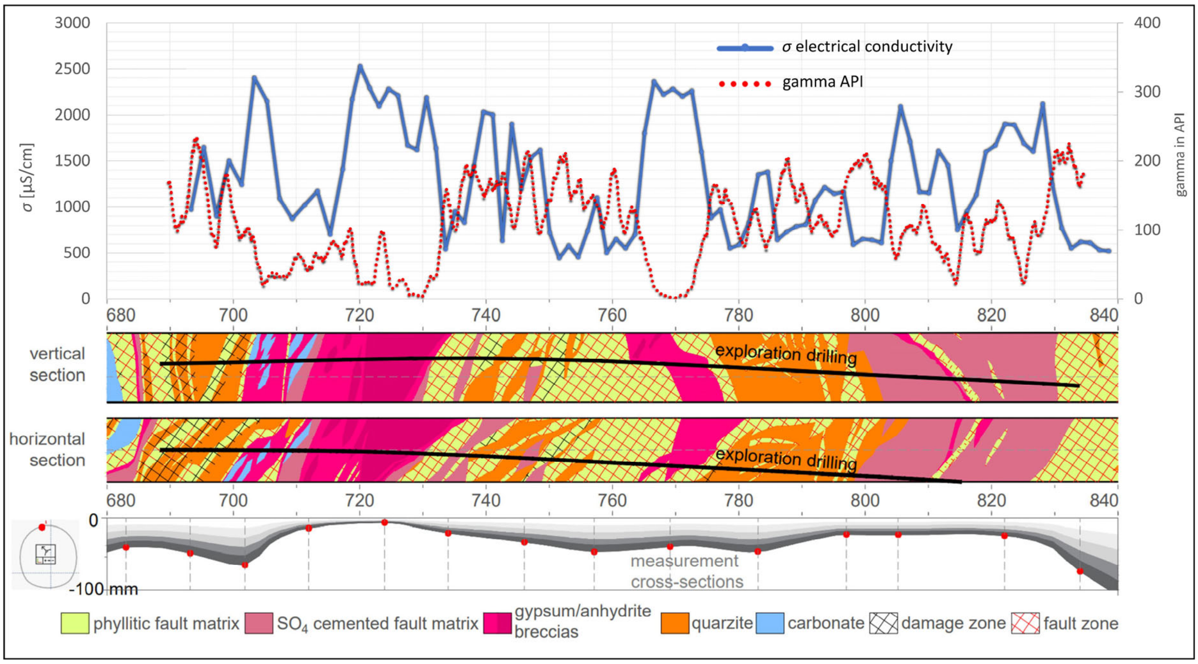

Fig. 4: Evaluation of exploration results. Comparison of exploration data with geological documentation of the excavated tunnel and crown settlements.

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