Risk Management in Tunnelling – A Joint Approach of all Involved

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ABSTRACT

Risk management in tunnelling requires a joint approach of all parties involved in the project, the clients' representatives, the designers and the contractors as well as the site supervision and the geological and geotechnical experts on site. Only a common approach and a joint goal of a safe and economical construction will lead to a successful and satisfying project completion. The paper presents the Austrian approach for tunnels and underground structures based on the Austrian Guideline for the Geotechnical Design of Underground Structures (Ref. [1]). The procedure is backed with examples of the actual implementation in major tunnel projects.

Risk management in tunnelling projects starts not only with the start of the construction but already during the initial design phases. All geotechnical risks have to be evaluated by the design team prior to the start of the actual design works and be covered as much as possible by the solutions provided. Any remaining risks must be acceptable as to be handled during construction and will be considered in the so called geotechnical safety management plan which is prepared during the tender design and is part of the contract documents.

The geotechnical safety management plan is a design document which includes information about the expected behaviour of the tunnels under consideration of the underground conditions and support measures. The expected behaviour is to be referenced by alarm and alert values for deformations, water inflow, stresses etc. The content covers also all roles and responsibilities of all parties involved as well as contact information of the named personnel. All processes and procedures for the regular as well as for exceptional cases are presented and intervention measures defined.

During tunnel construction the team dealing with the geotechnical safety management on a daily basis typically consists of the geotechnical and geological experts on site and the site supervision, which are on behalf of the client on the one side and the contractor on the other side. During daily routine meetings the monitoring results are analysed and in case of necessity respective measures are taken. The designer will be included as to adapt the design accordingly and update the geotechnical safety management plan if required.

The theoretical background will be shown in practice by experiences made during major tunnelling projects in Austria such as Semmering Base Tunnel or Tunnel Lainz and Tunnel Wienerwald.

Semmering Base Tunnel is a 27 km long railway tunnel in a mountainous environment with an overburden of up to 900 m, which is currently under construction.

The total length of the two adjacent projects Tunnel Lainz and Tunnel Wienerwald is app. 26 km with 24 km being built by means of mined tunnelling method. Tunnel Lainz is mainly located in an urban environment under shallow overburden and for Tunnel Wienerwald the overburden ranges from about 10 m at the portal areas up to a maximum of 200 meters. The tunnels are already under operation successfully.

Key Words: Risk and safety management in tunnelling

1. INTRODUCTION

Tunnelling projects will always be carried out with certain risks allocated. Even with a sophisticated design as well as a wide ranging investigation campaign remaining geological and geotechnical risks and risks connected to the construction procedure cannot be avoided. The underground conditions include a variety of geological, geotechnical and hydrogeological aspects which cannot be predicted in the very detail. In addition certain simplifications and assumptions in the modelling of the underground have to be made during the design, which also results in a certain degree of uncertainty.

In order to minimize such remaining risks for the owner, the contractor and especially for the public during construction the designer has to create specific tools for implementation by all parties involved during construction.

The geotechnical safety management is such tool and will be created by the designer during the preparation of the tender documents and is part of the works contract eventually. The following chapters will describe the creation of the documents required for the safety management and its implementation during the construction phase.

2. GEOTECHNICAL SAFETY MANAGEMENT PLAN

2.1. General approach

The general approach is based on the philosophy to evaluate geotechnical risks, take appropriate design measures to eliminate risks and in case of remaining, acceptable risks to develop means and measures to handle these during construction. Possible results of accepted remaining risks shall be limited to a minimum in the outcome in terms of financially or timely aspects.

By the application of the observational method according to Eurocode 7 [1] the expected behaviour of the system tunnel and underground shall be compared to the actual behaviour in the field. The safety management plan includes all the information required for carrying out such task and dealing with any unexpected situations. It defines the roles and responsibilities for all parties involved.

2.2. Evaluation of geotechnical risks

In the majority of tunnel projects the designer is dealing with a heterogeneous underground and varying geotechnical conditions. Based on experience and analyses possible failure or hazard scenarios have to be evaluated under consideration of the specific project environment. Such scenarios can include the following:

- Instability of the tunnel walls
- Block failure
- High utilization of load capacity
- Failure of the support
- Swelling
- Unexpected water inflow
- Toxic gases
- Exceeding deformations
- Exceeding settlements
- Exceeding vibrations

The types and range of risks have to be evaluated in a close cooperation between the engineers, geologists, hydrogeologists and any other specialists required for specific circumstances. All possible scenarios have to be considered and summarized in a clear and unmistakably form.

2.3. Consideration of geotechnical risks in the design

Once the geotechnical risks allocated in the project are identified the design team has to develop solutions for compensation of such risks. Procedures including support measures, heading concepts or pre-treatment of the underground have to be created and their adequacy has to be confirmed by analyses. Such analyses can include analytical as well as sophisticated two or three dimensional calculations, where all excavation steps are modelled in detail. Figure 1 shows an example for a three dimensional finite element calculation for a complex tunnel heading.

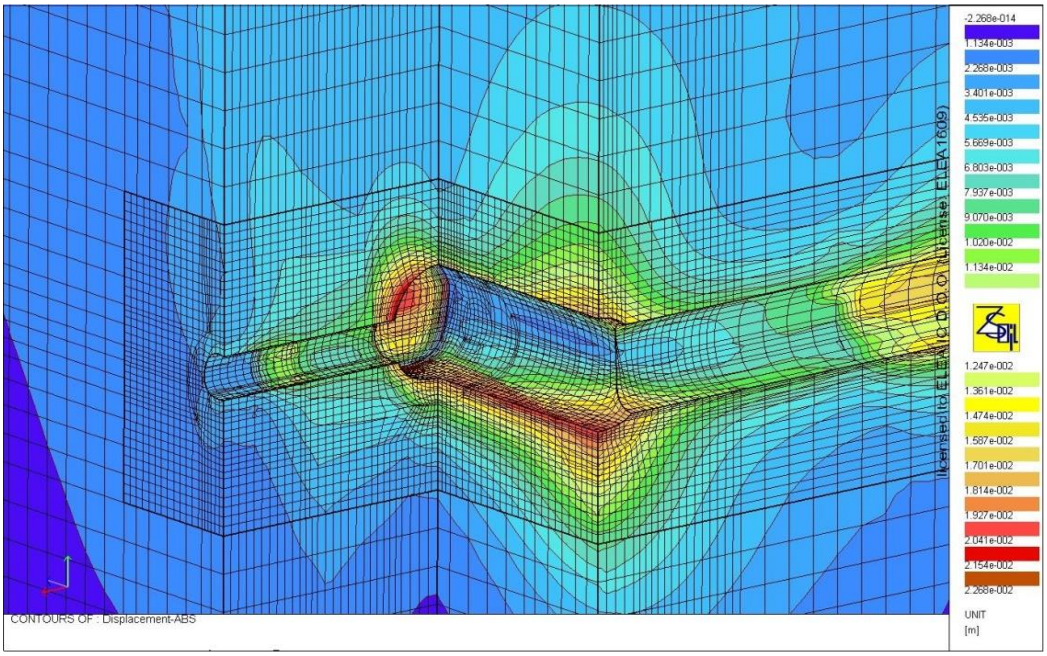

Figure 1. 3D calculation result

The designed support measures have to be presented in a clear manner for implementation in the field. Figure 2 includes a typical example for support measures developed for certain underground conditions where high deformations are expected. In this particular case lining stress controllers (LSC elements) shall enable higher deformations without exceeding the load capacity of the shotcrete lining.

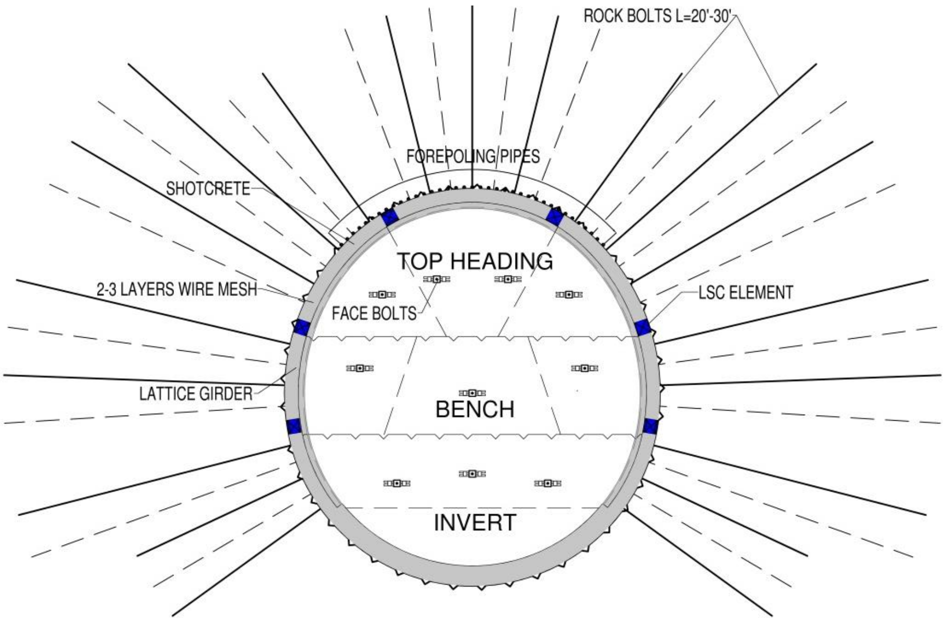

Figure 2. Support measures incl. lining stress controllers

Any remaining risks in the project shall be acceptable for all parties involved in the design and shall be in accordance to all requirements and limitations given by the project environment.

For the remaining risks the designer has to provide tools for the team present at the construction site to control that the system behaviour of the tunnel, support and underground, is in accordance to the results of the design. The definition of the expected behaviour as well as alert and alarm levels for various measurable data has to be provided, which are based on the results of the analyses carried out during the design phase.

The geotechnical safety management plan shall ensure a safe and economic construction process under consideration of uncertain aspects and define the expected behaviour and its control elements and mechanisms. The geotechnical safety management plan includes as a minimum the following content:

- Contact details of all project parties
- Definition of tasks for each party
- Meeting schedules and procedures
- Monitoring program and frequency
- Flow of information
- Definition of the expected (“normal”) behaviour
- Alarm and alert values
- Organization in case of unexpected behaviour
- Case dependent counter measures

During construction the geotechnical safety management plan shall be adapted in accordance to the actual system behaviour and experiences made on site. In case of deviating system behaviour or any other unexpected phenomena the reason and source shall be evaluated and after a detailed analysis the design adapted accordingly.

In case of deviations the reason has to be evaluated and the respective measures have to be decided. This can be an adaption of the foreseen support measures or a re-evaluation of the provided data regarding the underground conditions

2.4. Risk management during construction phase

The safety management plan and the related design documents such as drawings or technical specifications shall include all tools required to control the expected system behaviour. The observational approach according to Ref. [2] is taken to confirm the expected or detect any unexpected behaviour.

Numerous data are measured and monitored by the on-site monitoring team in order to provide information about the following aspects:

- Tunnel displacements
- Loading or strains of shotcrete lining and bolts
- Settlements of surface, objects or infrastructure
- Ground deformation near objects
- Deflection of infrastructure or objects
- Vibration
- Water inflow
- Occurrence of gas
- Swelling phenomena (displacements)

Figure 3 shows a typical monitoring arrangement for a situation with shallow overburden including settlement points and extensometers on the surface, monitoring targets, invert levelling and extensometers in the tunnel.

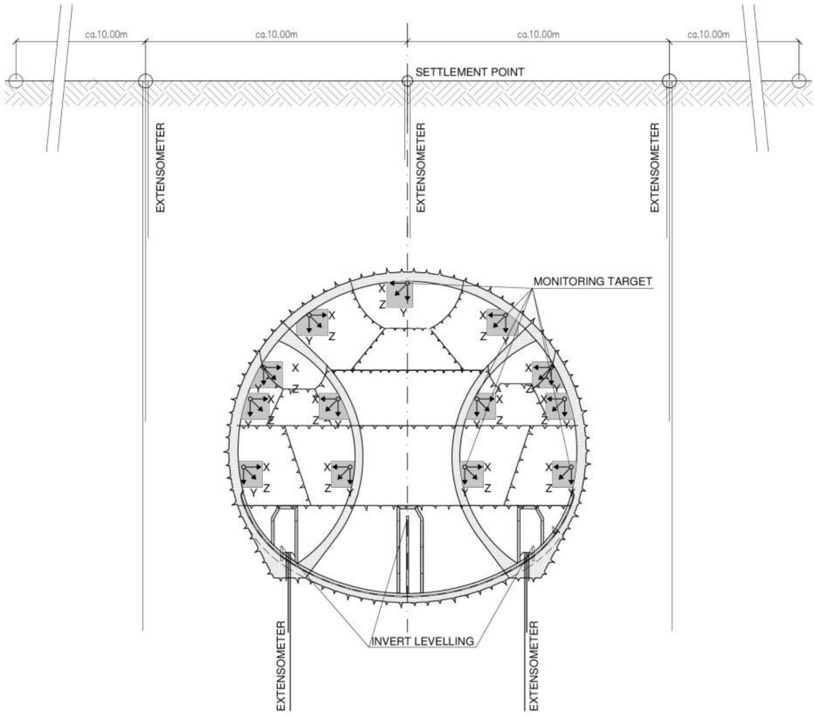

Figure 3. Typical monitoring section

The measured data are provided to the on-site geotechnical engineers, who are the connection between the design team and the construction site. The geotechnical engineer evaluates and analyses the information and compares the actually observed to the expected behaviour defined by the above mentioned information.

The analyses and evaluation of the 3D displacement monitoring for example include time-displacement diagrams, distance-displacement diagrams, deflection curves (state diagrams) and trend lines (see [6]). In addition the geotechnical engineer evaluates inclinometer and extensometer readings as well as stresses or strains in the shotcrete lining and bolts. Figure 4 shows an example for a time-displacement diagram for all monitoring targets of an individual monitoring section.

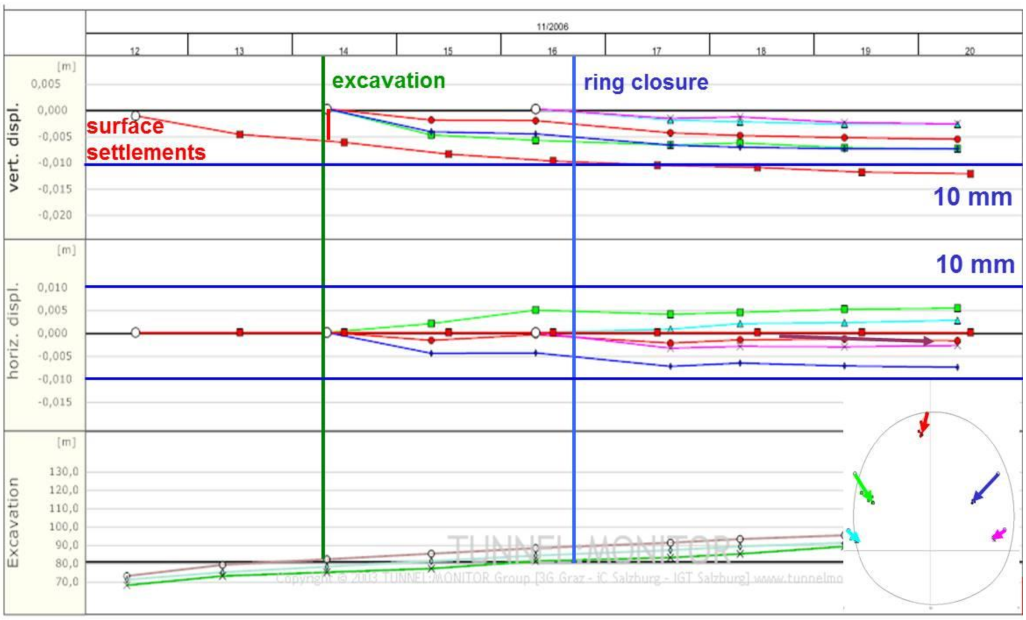

Figure 4. Typical time deflection curves

In case of deviating system behaviour it is the task of the geotechnical engineer together with the designer developing appropriate solutions. Such solutions can include the adaption of the support measures or heading concept, or rechecking the assumptions made during the design phase.

The results of the evaluation and interpretation are provided to the designer, the site supervision, geologists and contractor on a daily basis. Regular on-site meetings are held in order to discuss the results and define appropriate measures in case of necessity.

It is of utmost importance that the different parties are in a constant exchange of information and discussion as to realize a safe construction process. With such approach a possible event triggered by remaining risks shall be detected at an early stage and appropriate countermeasures shall be set.

3. ON-SITE EXAMPLES

The following chapters include examples of the implementation of the geotechnical safety management in major tunnelling projects in Austria.

3.1. Semmering Base Tunnel

3.1.1. Introduction

Semmering Base Tunnel, one of the major infrastructure projects in Europe, consists of two 27.3 km long single-track tunnels, numerous cross passages and a complex underground emergency station with two, more than 420 m deep, shafts. Temporary access is provided by a 1 km long access tunnel, with two 250 m subsurface shafts, and two 100 m shafts from the surface.

Various types of large caverns are planned, which are either foreseen temporarily for construction purposes such as intermediate access and space for site installations, or permanently for the underground emergency station. The dimensions of the larger caverns are in the range of 25 m by 16 m.

The maximum overburden above the caverns is app. 500 m in difficult geological conditions with large fault zones and extensive water inflow, which require complex heading concepts, extensive support measures and partially special ground improvement works such as grouting.

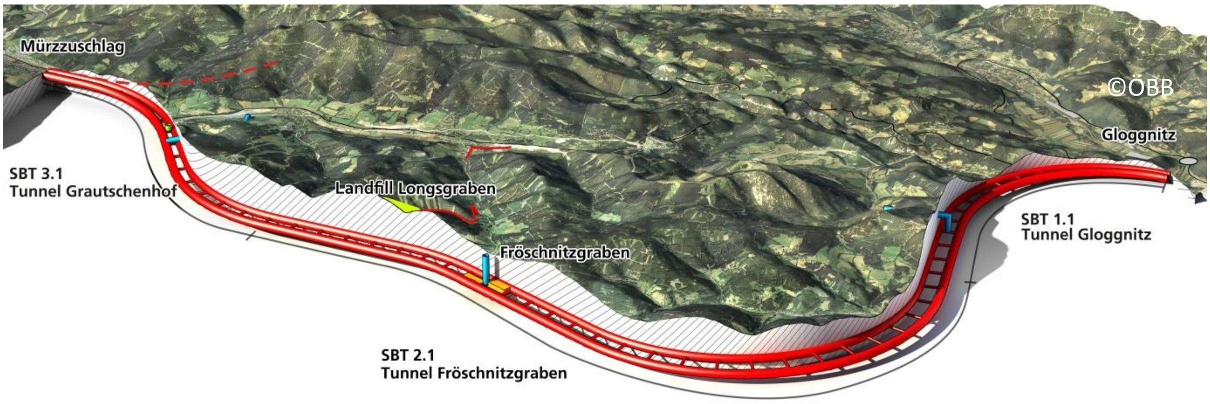

Figure 5. Semmering Base Tunnel

3.1.2. Application of the Geotechnical safety management

A representative example for the application of the geotechnical safety management is presented, taken from the excavation of the 1 km long access tunnel Göstritz. For the described section, the geological prognosis indicated comparatively favourable conditions with the tunnel mainly situated in compact carbonatic rocks, such as Rauhwacke and carbonatic brecchiae. The tunnel design based on this prediction foresaw a cross section with an open invert, a light shotcrete lining with a thickness of 10-20 cm and round length of 1.70 – 2.20 m. Expected deformations were in a range of a few centimetres. The warning level within the Geotechnical Safety Management Plan (GSMP) was defined as an exceedance of the expected displacements (in this case a prognosis value of 25 mm) by 25%.

During excavation, the encountered conditions in the subject section all in all matched the expected. The excavation advanced in carbonatic brecchiae. Geotechnical monitoring was performed using absolute 3D displacement monitoring on a daily basis. Monitoring sections (MS) were arranged at a distance of approx. 10 m, and consisted of five displacement targets each.

Complementary to displacement monitoring, a back analysis of the shotcrete lining utilization was performed using the so called 'hybrid method' developed by Macht, Hellmich and Lackner (Ref. [3], [4], [5]). This method evaluates the strains in the shotcrete lining from the observed displacements and combines it with a thermos-mechanical constitutive model for shotcrete. For daily use, this procedure was integrated in the software package TunnelMonitor (Ref. [7] and see Figure 7).

Up to chainage 960, the observed displacements were within the expected range. In MS 970, a significant increase of displacements in the right sidewall was observed, which got more and more pronounced with advancing excavation (see Figure 6).

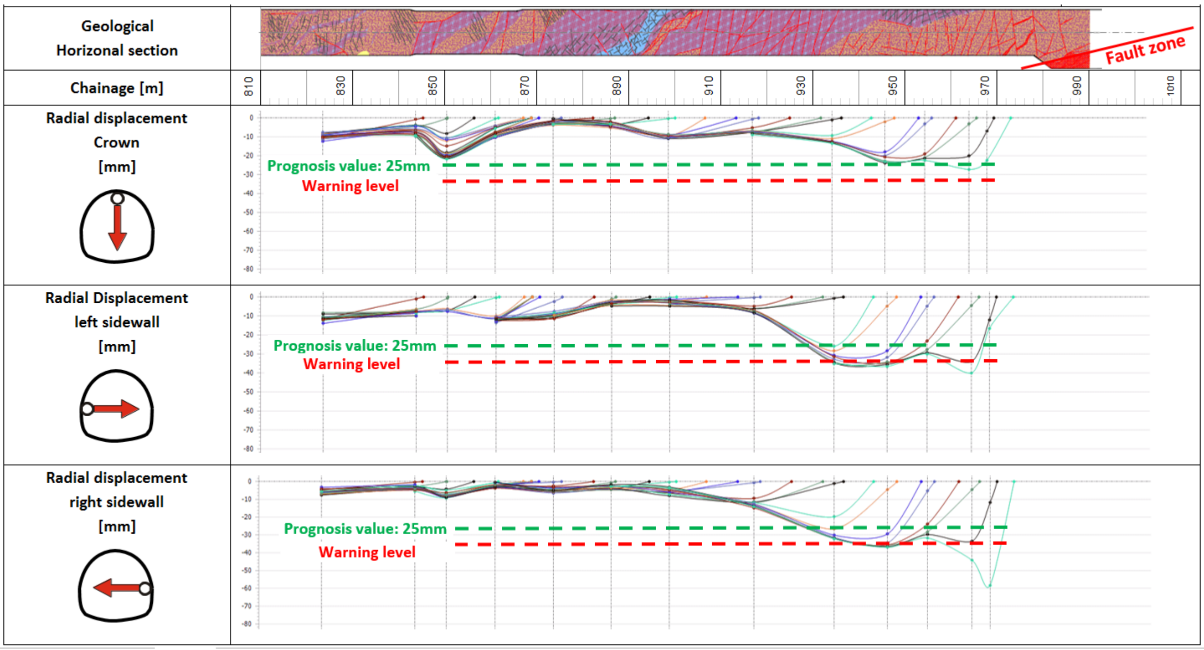

Figure 6. Geological situation and spatial displacement development, access tunnel Göstritz

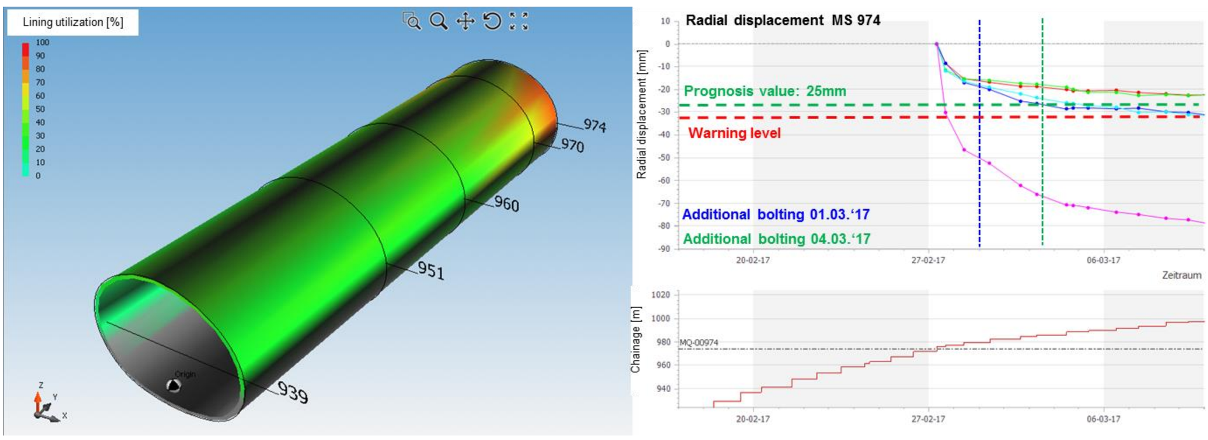

Figure 7. Lining utilization (left) and time-displacement history MS 974 (right)

Warning levels were exceeded at the third reading taken (i.e. 3 days after excavation), while the encountered conditions at the tunnel face did not change significantly. Site engineers expected a fault zone crossing the tunnel somewhere ahead of the face as the reason for this. At the same time, the back calculation of lining utilization showed a high utilization in the right sidewall (see Figure 7).

Following the procedures for unexpected behaviour in the GSMP, additional rock bolting was applied in the sidewalls. Additionally, exploratory drillings were performed to investigate the conditions ahead of the face, without indicating changing conditions. High displacement increments on the following days did not indicate a significant improvement of the situation. Therefore a second supporting campaign was carried out, which finally lead to a stabilization of displacements (see Figure 8). Advancing excavation finally confirmed the assumptions, as a major fault zone with a thickness of more than 10 m was encountered, crossing the tunnel in an acute angle of approx. 20° from right to left. Due to the unfavourable orientation of the fault zone it was not met in the exploratory drillings.

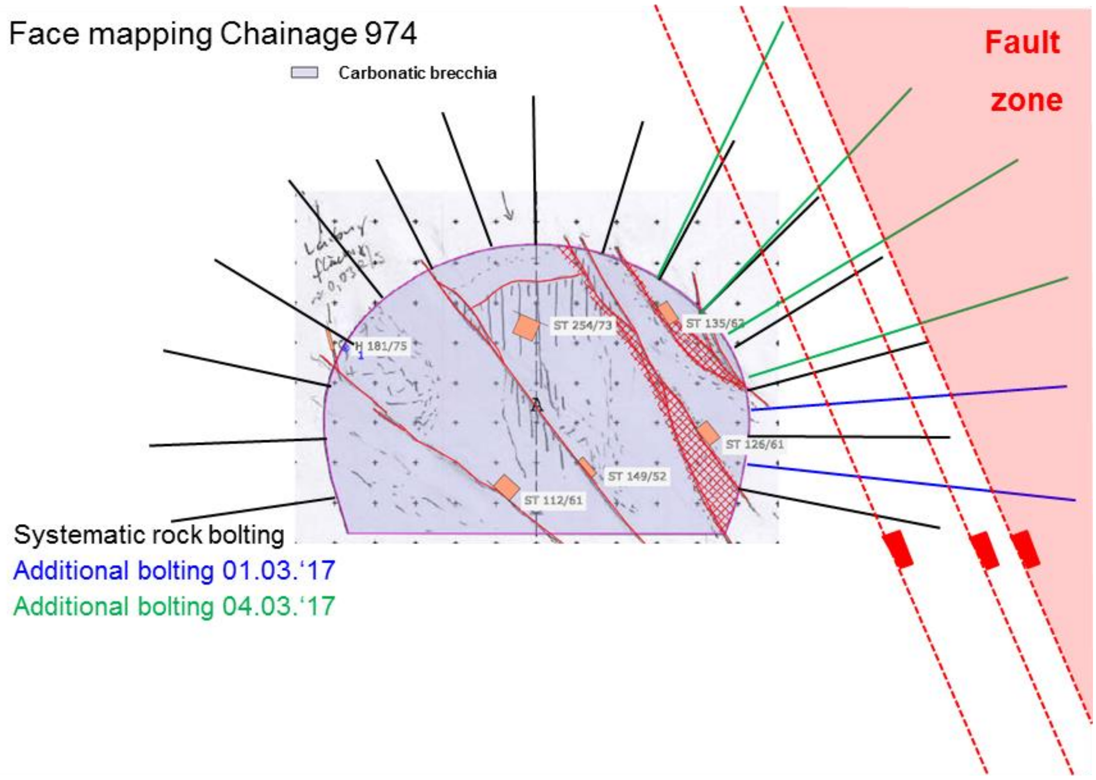

Figure 8. Encountered geological conditions at the face, geotechnical model at MS 974

A consequent application of Geotechnical Safety Management in this case lead to a successful solution of an unexpected situation. Furthermore, the additional knowledge gained during this situation led to a subsequent adaption of support measures for the upcoming tunnel sections located directly in the fault zone.

3.2. Tunnel Lainz and Wienerwald
3.2.1. Introduction

The total length of the two adjacent projects Tunnel Lainz and tunnel Wienerwald is app. 26 km, whereof 24 km are built by means of mined tunnelling method. Various structures such as single or double track tubes, conical shaped widening sections or emergency galleries and shafts are implemented. Considerable sections of the alignment pass under residential areas or major traffic infrastructure with shallow overburden. In contrast other segments have to cross wide fault zones with an overburden of up to 200 m.

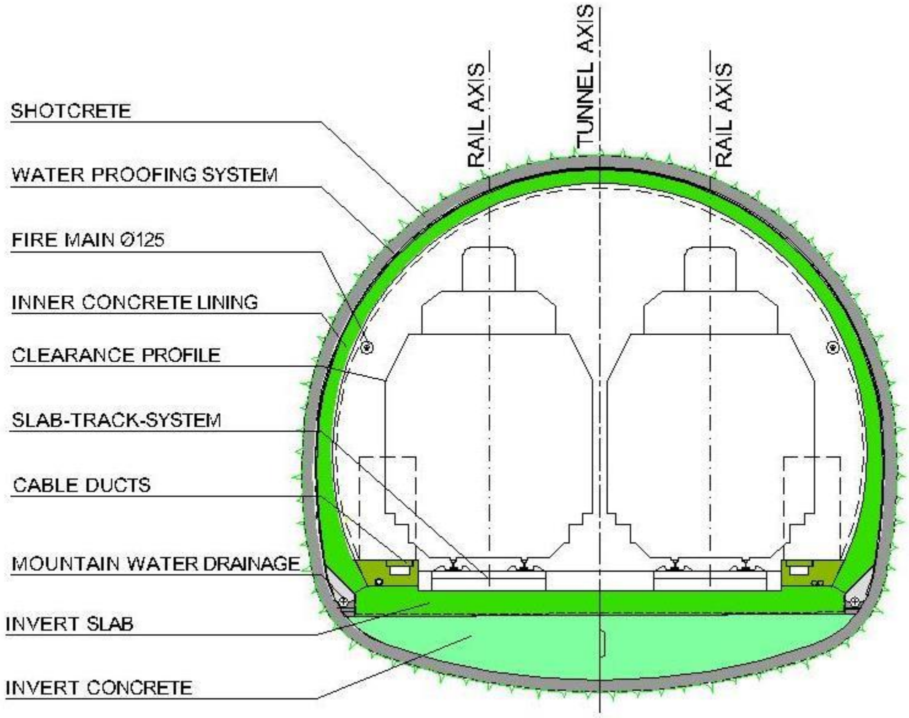

Figure 9. Double track tunnel

3.2.2. Application of the Geotechnical safety management

Along the alignment of the Lainzer und Wienerwald Tunnel numerous residential areas (see Figure 9) are influenced by sound and vibration due to construction. Some of these buildings are located right above the tunnel or within less than a tunnel diameter. Figure 9 shows the arrangement of monitoring sections for a certain location with shallow overburden.

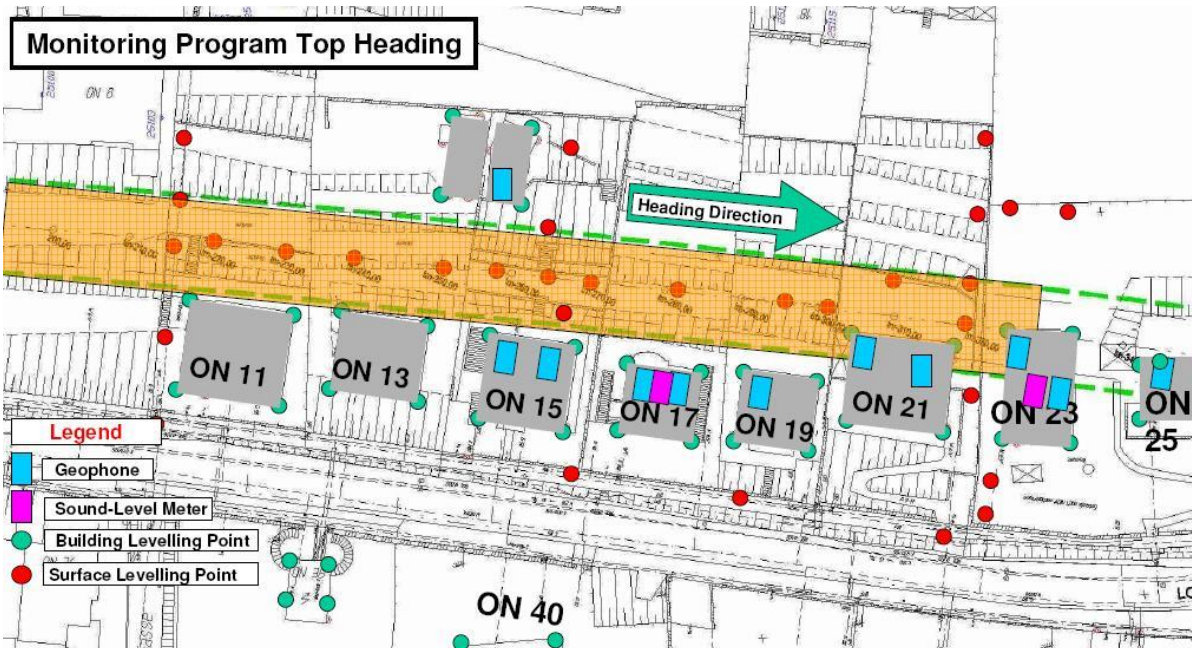

Figure 10. Sound-level meter system/vibration monitoring system

The safety management plan includes alarm and alert values for noise and vibration separated for day and night time. The scope of the work for the on-site monitoring team included the installation and supervision of the sound-level meter and the vibration monitoring system. A detailed evaluation of vibrations due to blasting and interpretation of the monitoring results was carried out on a daily basis. Based on the results adaptions of the excavation sequence as well as the blasting pattern were carried out.

The permanent monitoring equipment was activated by reaching a trigger value. Retrieving of the data was also possible via a GSM modem for further detailed evaluation. In addition, all monitored data were automatically visualised on an internet platform with a regular update frequency. The equipment also allowed immediate notification by SMS to a mobile telephone of the construction supervision personnel when alert or alarm values were exceeded. Figures 11 shows exemplary the results of the vibration monitoring in a specific diagram representing a duration of 24 hours.

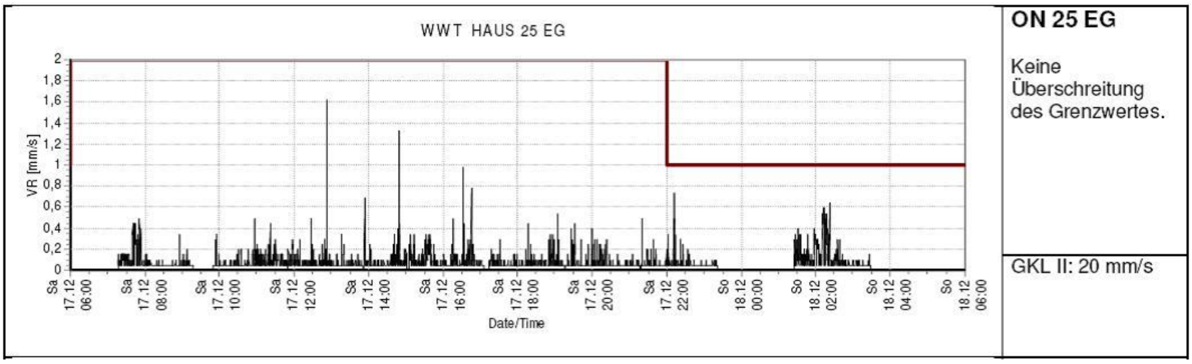

Figure 11. Vibration monitoring (different limit values day and night time).

4. CONCLUSION

Tunneling projects are always prone to remaining risks and uncertainties respectively, as the main component is the underground, which cannot be predicted in the very detail. Therefore, appropriate tools have to be provided as to control and confirm the expected behaviour of the underground and the excavation and to meet unexpected situations.

One of these tools is the geotechnical safety management plan, which includes all means and measures for a proper handling of all possible occurrences during construction.

A close team of experts in the design and on-site including geotechnical engineers, geologists, monitoring experts, site supervision and the contractor has to deal with the given tasks within a daily routine and based on a pre-defined evaluation procedure. This common work leads to a successful project in terms of safety and economical aspects.

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