Geotechnical Safety Management on Site

W. Schubert
Graz University of Technology, Austria

ABSTRACT: The uncertainties in the ground model and consequently the design of tunnels call for an observational construction approach. To allow for safe and economical tunneling a safety management plan has to be implemented. Basis for the safety management plan is the design, which continuously is updated, as information increases. The contribution deals with following topics:

- Targets of the Safety Management
- Basic elements and structure of the Safety Management Plan
- Parties involved and their responsibilities
- Determination/Definition of the expected behavior; definition of warning and alarm levels/criteria
- Monitoring program; layout and frequency of monitoring in accordance with expected behavior and boundary conditions
- Information and communication flow
- Action plan; organization, and mitigation measures in case observed behavior deviates from the expected
- Management of a crisis

A key element for establishing realistic warning and alarm criteria is a profound understanding of geotechnical processes and the ground-structure interaction. Thus a meaningful plan can be only established in close cooperation between designers, geotechnical experts, and the site management. Advanced tools for monitoring data evaluation and interpretation assist in establishing expected behaviors and check the monitored values against the warning and alarm criteria. The implementation and execution of safety management plans on site will be shown with case histories from the Wienerwald railway tunnel in Austria

1 INTRODUCTION

Even with an excellent investigation, testing, and ground characterization program, as well as the application of up to date design methods, uncertainties with respect to geological conditions and ground reaction remain during construction. To obtain safe and economical tunnel construction, an observational approach is required.

Rules, methods, definition of responsibilities, etc. are laid down in a safety management plan, which is basis for all safety relevant actions on site. The procedures outlined here reflect the practice, as executed by the Austrian Federal Railways (OeBB, 2004)

2 TARGETS OF A SAFETY MANAGEMENT PLAN

The targets of the Safety Management Plan are:

– Allow for safe and economical tunneling in not completely known conditions
– Definition of preparatory steps, methods, and procedures for the implementation of the observational method
– Definition of responsibilities and procedures to prevent unfavorable effects or stability problems
– Definition of required procedures and measures in the case of a crisis to avoid damage, in particular to third parties.

3 BASIC ELEMENTS

The geotechnical safety management plan consists of following basic elements:

– Definition of the parameters to be observed
– Definition of the expected behavior of the underground structure during construction
– Definition of monitoring methods, locations, amount, and reading frequency.

- Definition of warning and alarm levels
- Organisation required to conduct monitoring, data handling, evaluation and interpretation and communication structure between the paties involved
- Procedures and measures in case the behaviour deviates from the expected one
- Procedure for the case of a crisis, including alarm criteria, organisation, and protection priorities
- Framework construction plan
- Updating of the prediction made during the design, as new information is available

The geotechnical safety management plan consists of two parts, the first being valid fort he whole project, the second part containing the detailed regulations for different sections with different ground or boundary conditions.

4 PARTIES INVOLVED AND THEIR REPONSIBILITY

In the general part of the Safety Management Plan the function, addresses, phone and e-mail numbers of all parties involved in the project are listed. Also listed are the contact details of institutions and organizations, which have to be informed in the event of a crisis, where third parties are at risk.

In addition the general part contains a detailed description of the responsibilities of the individual positions in the project.

5 DEFINITION OF EXPECTED SYSTEM BEHAVIOUR AND WARNING AND ALARM CRITERIA

The designer defines the expected system behaviour of the tunnel during the excavation and the influence of the tunnelling works on surface and subsurface structures being influenced for the single sections of the tunnel. This serves as a basis for the geotechnical engineer on site, who has to evaluate the monitoring results.

Following details have to be given:

- Deformations of the tunnel
- Surface settlements and settlement trough
- Deformations of the ground in the vicinity of critical objects
- Deformations in the influence area of retaining structures
- Influence of tunnel works on utility lines and indication of advance mitigation measures

6 MONITORING PROGRAM

The monitoring methods have to be selected to capture the parameters relevant for the safety. The monitoring intervals shall be frequent enough to detect unfavourable developments in time, and the evaluation of the monitoring results has to be sufficiently rapid in relation to the possible evolution of the system.

Monitoring includes observation of the geological and water conditions, measurements of displacement on the surface, the ground, and the tunnel, as well as measurement of vibrations if required.

Type and amount of monitoring, as well as minimum reading frequency for the single sections of the tunnel are put down in the Framework Construction Plan.

6.1 *Specification of monitoring criteria and control measures*

For the single parameters observed, following is specified for each section:

- Expected behaviour
- Method of observation evaluation of data
- Criteria for attention level
- Criteria for the warning levels 1 to 3
- Mitigation measures
- Alarm criteria for the warning levels 2 and 3
- Method of intervention in case of an alarm

6.2 *Warning levels*

In case the actual behaviour deviates from the predicted one, one of the four warning levels is applied, depending on the severity of the deviation.

The attention level applies, when the actual behaviour, respectively the predicted actual behaviour exceeds the expected one or is close to the limits specified by the authorities.

The criteria for warning level 1 are set at significant deviations from the expected behaviour, but with a reasonable safety margin against failure.

The criteria for warning level 2 are reached in case of progressive deformation development, low margin of safety, or local failure. When level 2 is reached, alarm is announced. Warning level 3 applies, when warning level 2 is reached and third parties are affected.

Conditions for resetting a warning level are the stability of the tunnel, or when observation results show that objects or utilities are not influenced, as well as, when the mitigation measures have proven to be effective.

6.3 *Monitoring methods and extent*

Monitoring methods in general include documentation of geological and hydrological conditions and interpretation, visual observations in the tunnel and on the surface, displacement measurement, and vibration measurement, measurement of water and gas quantity/concentration.

Displacement monitoring includes measurement of surface points and objects, inclinometers, extensometers and 3D displacement monitoring of the tunnel itself.

The basic monitoring layout and minimum reading frequency is determined by the designer and the geotechnical on-site engineer, and is shown in the Framework plan. Detailed adjustments of the program are made by the on-site geotechnical engineer according to the requirements.

6.4 *Execution of measurements*

The owner usually takes the responsibility for making the geotechnical measurements, while the contractor is responsible for the correct position of the tunnel.

The survey team receives the instructions for the type of measurements and minimum reading frequency from the geotechnical engineer. The evaluation of the data has be done in a way, that the results are available for the geotechnical engineer within the same day of the reading.

7 INFORMATION FLOW

In general everybody involved has to report unusual observations immediately to the Engineer and the geotechnical on-site engineer, as well as the contractor.

To allow for an efficient flow of information and up to date access to evaluated data, a ftp-server is installed. The parties involved in the evaluation of data have to store the evaluation results on the server immediately after evaluation. All parties involved in the project have access to the data stored on the server.

Preferably a daily joint site visit of the representative of the contractor, the Engineer, the geotechnical on-site engineer and the geologist is made. After evaluation of the monitored data, a meeting among the parties mentioned above is held, where information is exchanged, and necessary measures are decided.

In case of deviations from the routine, for example due to an increased or changed reading frequency or unusual events requiring a change of the routine, the geotechnical engineer informs the Engineer and the external expert about the storage of out of routine data by email or phone.

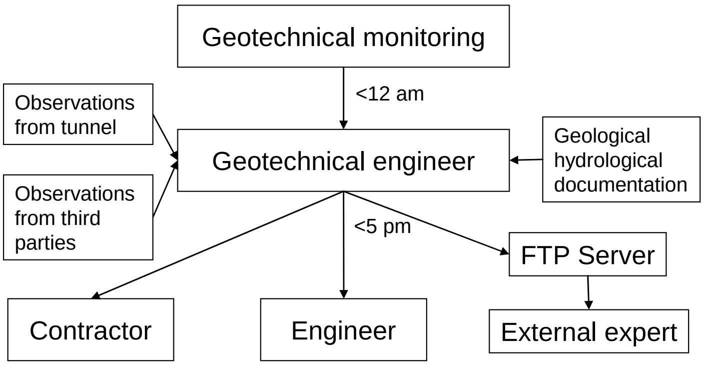

Figure 1. Routine safety relevant information flow

8 PRACTICAL APPLICATION

Besides the stability of the tunnel itself, the effects of the tunnel works on other objects and utilities is of particular importance. In the design those issues have been addressed, and consequently the design form the initial basis for the geotechnical safety management plan.

All critical objects and utilities are listed in a table as well as the acceptable impact on those structures by the tunnelling works. The expected “normal” behaviour of the tunnel, its influence on the surface and objects is quantified. For a timely detection of deviations from the normal behaviour it is not enough to define final deformation values, but also the timely and spatial development. It has shown beneficial to specify expected deformations in relation to the face distance, for example in distances of ½ diameter and 2 diameters in addition to the final displacements. Thus it is possible to detect deviations in time to initiate strengthening or mitigation measures.

The table also includes the methods of observation and evaluation of the safety relevant parameters. For example for the assessment of the stability of the face usually only visual inspection is available, while for the deformations of the tunnel and the surface geodetic and geotechnical instrumentation can be used. The method of evaluation in this case can reach from simple plots of displacement histories (time-displacements plots) to more sophisticated ones, like the trend of the displacement vector orientations.

Following the definition of the expected behaviour the warning and alarm criteria are listed. For the tunnel displacements or surface settlements, the trigger for the attention level might be taken at the expected values, while the criterion for the warning level 1 might be an increase of deformations in the order of 20% above the expected values. The mitigation measures in this case would be an increase in the support if only the tunnel displacements exceed the warning level. If the warning criterion is reached also on the surface, additional face support, a decrease in the round length and the excavation rate might be the recommended mitigation measures. In the case of houses and other objects in general the criteria are admissible distortions. The observation of trends, as the tunnel progresses allows a timely detection of unfavourable developments, provided that appropriate tools are used for the data evaluation.

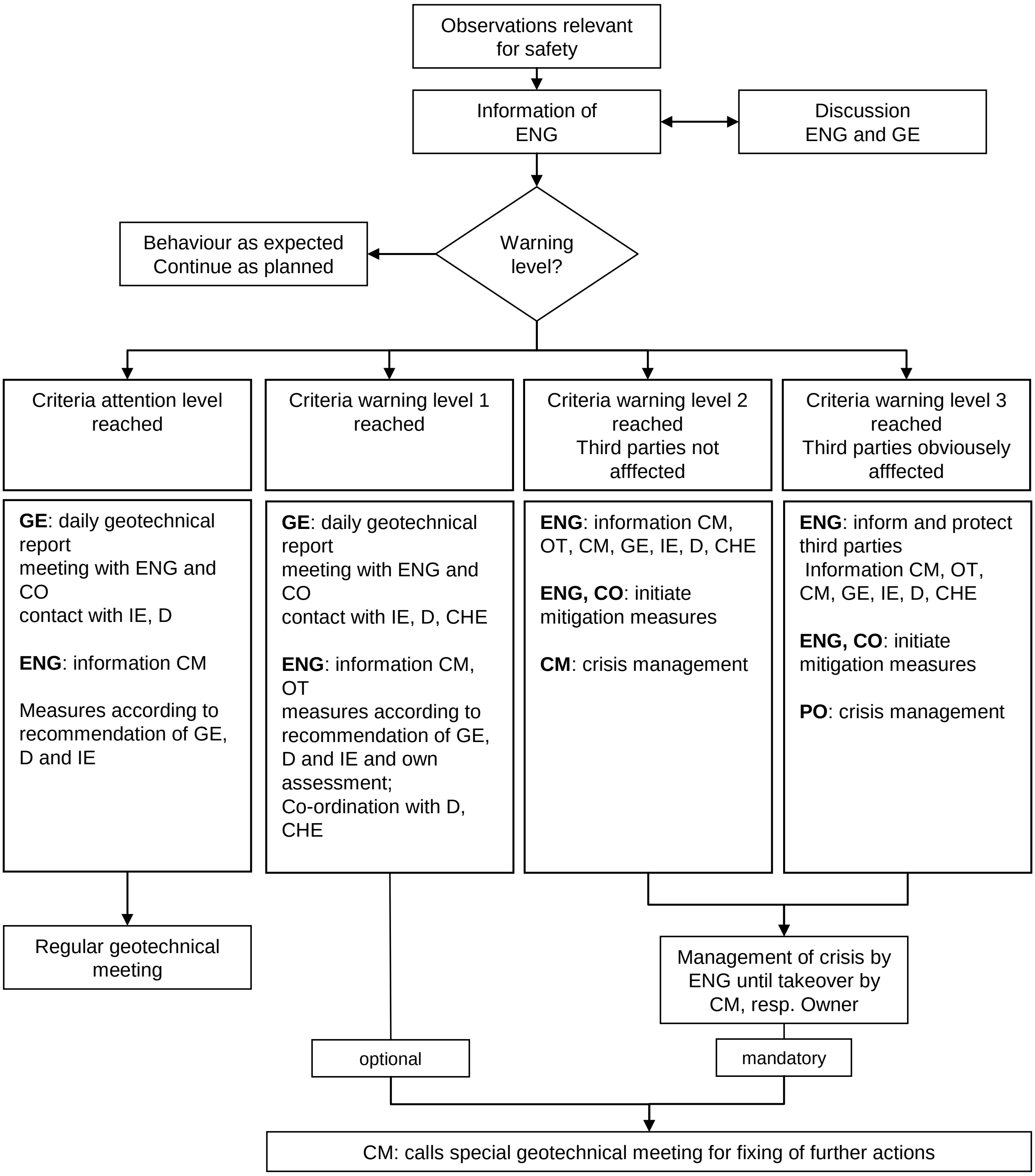

Figure 2. Procedure in Geotechnical Safety Management Plan; Abbreviations: GE - Geotechnical Engineer on site, ENG - Engineer, CO – Contractor, IE – Independent Expert, D – Designer, CHE – Checking Engineer, CM - Construction Management, OT – Owners technical representative, PO – Owners Project Representative

While the attention level and warning level 1 are considered to be managed with relatively low level mitigation measures, levels 2 and represent serious hazards for the structure or third parties. Top priority in those cases has the public safety, followed by the safety of those involved in the project, and finally the stability of the structure.

Naturally in the case of a crisis also parties are involved, which are not familiar with the details of the construction and the evolution of the system. Thus a good routine documentation of all facts is essential to quickly convey the critical developments, and to arrive at mitigation measures appropriate to the situation. All parties involved must be aware, that in the case of a crisis, appropriate decisions can only be made if the data basis is excellent. As a crisis usually is unexpected, the monitoring and data quality have to be at a top level at all times.

Good preparation therefore is essential. A list of all those to be protected, as well as the contact details of all parties and organisations to be alerted has to be prepared well in advance. Also means, methods, and equipment required to conduct appropriate mitigation measures must be available on site at al times.

9 APPROPRIATE TOOLS FOR DATA ACQUISITION AND EVALUATION

It can be observed, that on many sites the methods of monitoring and data evaluation have not developed beyond the status of the 1970ies. Still convergence tape measurements seem to be the state of the art, while the only evaluation method is a plotting of the displacements versus time.

Since more than twenty years geodetic 3D displacement measurement techniques allow to gain much more information. Parallel to the advance in measurement technique, methods of data evaluation have been improved. Plotting of displacements versus time nowadays is only one method of visualizing the results of monitoring. Deflection line diagrams, trends of displacements, or ratios of different displacement components, allow a much better assessment of the mechanical processes during tunnelling, than was possible with the traditional methods.

Efficient software for the data processing and evaluation is available (Tunnel:Monitor, 2006; GeoFit, 2005). In particular the possibility to predict the development of the displacements in relation to face advance and time after a few readings allows a timely detection of unfavourable developments (Grossauer et al., 2005).

10 CASE HISTORIES

Two case histories from the Wienerwaldtunnel, a double track railway tunnel located at the western outskirts of Vienna shall illustrate the practical application of the safety management plan.

On November 21st, 2005 the geotechnical engineer on site detected, that the development of the surface settlements at the measuring sections 390 and 400 reached the criteria of warning level 1 (criterion 37,5mm). Via e-mail he informed the Engineer, the construction management, the technical representative of the owner, the contractor, and the external tunnel expert. As a building is located close to the face and the displacement trends showed an increasing tendency, the geotechnical engineer proposed to change the excavation and support sequence, with a shortening of the ring closure distance of the temporary top heading invert. In a site meeting in addition the thickness of the shotcrete in crown and invert was increased, as well as the number of bolts starting from station 422. The increase in support and the reduced ring closure distance reduced the amount of the displacements in the tunnel.

Another unfavourable development was observed at the same tunnel around station 1.000. Obviously due to the influence of a fault zone outside the right sidewall, displacements increased in a progressive manner in measuring section 997 (see figure 3). The situation was assessed by the geotechnical engineer, the designer and the external expert. As the tunnel is located outside built up areas, no immediate action was required, but increased attention paid to the further development. Additional bolting was ordered and executed on a length of around 20 m. In addition, the tolerance for deformation was increased to 20cm. As a local phenomenon could have caused the increase, it was decided to continue with the excavation, while simultaneously mitigation measures were evaluated, should the additional bolting not show the desired effect. With the data available from July 16th, it was clear that the tunnel is in the process of stabilization, but total displacements would most probably exceed the deformation allowance (figure 4). Thus in an extraordinary geotechnical meeting, the previously discussed mitigation options were fixed. Those consisted of additional bolts, and the installation of three stripes of temporary invert with a length of 4m each. The excavation was stopped and the strengthening measures put into effect.

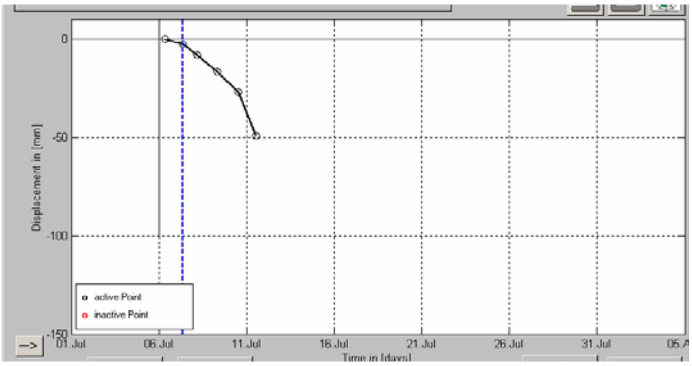

Figure 5. Development of vertical displacement of the right footing of the top heading

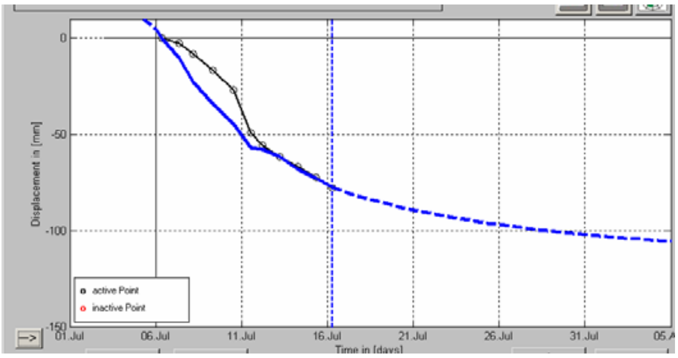

Figure 3. Predicted development of settlements (dashed line)

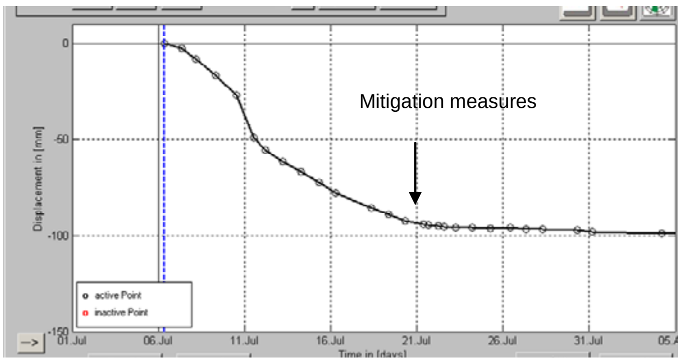

Figure 4. Development of displacements after mitigation measures were put into effect

Figure 5 shows, that the displacements came to a complete stop, as the strengthening measures became effective. No further problems were encountered in this section, even when the bench and invert were excavated, and the total deformations were within the tolerance.

11 CONCLUSION

Especially when tunnelling in sensitive areas with adjacent buildings and utilities, increased attention is required to minimize adverse influences caused by the tunnel works. A thorough planning and preparation is required to allow for quick and appropriate action in case of unfavourable developments.

For a successful establishment and execution of a safety management, all possible hazards have to be assessed prior to construction. Limitations of surface settlements, as well as criteria of serviceability have to be observed. A well structured plan of communication and action has to be fixed to allow for efficient response to unexpected or unfavourable developments. In addition the site has to be equipped with experienced staff, and appropriate software for efficient data evaluation. Up to date displacement monitoring evaluation software should have features to predict displacements with a few readings only in relation to time and tunnel advance, as well as the possibility to assess the degree of utilization in tunnel linings.

IT nowadays allows that also off site experts are fully informed about the performance of the project at all times, and can give advice whenever required, based on a sound information level. A precondition for complete information of all parties involved besides of the installation of a server is the continuous feeding of quality data and evaluations.

It has to be stated, that a safety management plan is not rigid, but requires updating, as more information about the ground and the system response is acquired during construction.

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