Geotechnical safety management for tunnels

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WHY SAFETY MANAGEMENT?

- Uncertainties in the ground model
- Spread of parameters
- Simplifications in the design

- Resulting residual risk has to be controlled and managed
UNAVOIDABLE?
UNAVOIDABLE?
REQUIREMENTS DURING DESIGN

- Assess possible range of behaviour
- Establish acceptable limits for expected behaviour
- Assign construction measures to meet requirements
- Establish concept for assigning excavation and support to ground behaviour and boundary conditions
- Identify safety relevant issues
- Develop targeted monitoring program
EXAMPLE: POTENTIAL BEHAVIOUR

- Potential failure mode: shearing along vertical joints
ASSIGNMENT OF EXCAVATION AND SUPPORT

To reduce probability of shearing along vertical joints, bolting in the sidewalls and shoulders is applied.
ELEMENTS OF SAFETY MANAGEMENT PLAN

- Detailed definition of expected (target) behaviour for section ahead
- Definition of parameters to be observed, observation methods, layout, reading frequency and evaluation methods
- Definition of warning and alarm levels and criteria
- Definition of contingency measures for each warning level
- Clear definition of responsibilities
- Action plan in case of reaching the alarm level
- Organisation plan and reporting structure
DEFINITION OF TARGET BEHAVIOUR

„Normal“ system behaviour can be defined by displacement characteristics or magnitudes
WARNING/ALARM CRITERIA

- Meaningful warning and alarm criteria establishment only possible, if normal behaviour is sufficiently known and defined.
- Besides absolute displacement values, development and characteristics of displacements or other monitored values or observations should be defined.
- Usually three levels defined:
  - Level 1: warning level reached, but no imminent stability problem.
  - Level 2a: imminent stability problem, only site affected.
  - Level 2b: imminent stability problem, effects on third parties expected.
CASE HISTORY

Actual development of displacements

Expected development of displacements

Proclamation of warning level 2 due to unfavorable trend of displacements; Initiation of mitigation measures
CONTINGENCY MEASURES

- Additional bolting on a length of about 20m was ordered and executed immediately.
- A set of additional measures, like installation of a temporary top heading invert was prepared, should the initial mitigation measures not show satisfying effect.
EFFECT OF MITIGATION MEASURES

Additional bolting
PREDICTION OF FURTHER DEVELOPMENT
FURTHER DEVELOPMENT

- Initial mitigation measures effective, but expected total displacements likely to exceed the allowed deformation
- To keep within deformation tolerance, top heading invert installed
- This measure stopped deformations practically completely
FURTHER DEVELOPMENT

Second set of mitigation measures
CONCLUSION

■ To efficiently reduce the unaviodable residual risk during tunnelling, besides a sound preparation in the design phase, a safety management procedure during construction is required

■ Modern monitoring and data evaluation methods have considerably expanded the applicability of the observational approach, but cannot replace sound engineering
Geotechnical safety management plan

Expected/ determined system behavior

- Identification of safety relevant issues
- Definition of parameters to be observed, observation methods, layout, reading frequency, and evaluation methods
- Definition of warning and alarm levels and criteria
- Definition of contingency measures for each warning level
- Action plan in case of an alarm
- Organization plan and reporting structure
- Up-dating if necessary

Remark: this is also recommended for TBM tunneling!
Geotechnical safety management plan – Organization plan and reporting

- Expected system behavior
- Observation of system behavior
- System behavior as expected?
- Updating of expected system behavior
- Reaction time existing?
- Face stability?
- Water inflow?
- Failure mode?
- ...?

- Settlemnts, displacements
- Stresses
- Warning and alarm levels
- Failure identification
- ...
Geotechnical safety management plan - Priorities

1. Protection of public safety
2. Protection of all members of the project team
3. Protection of stability of structure
Geotechnical safety management plan – Organization plan and reporting – “NORMAL BEHAVIOR”

- Owner / Client
  - Project manager
  - Site manager

- Contractor
  - Site manager

- Site Supervision
  - Head of site supervision

- Designer/ Experts

- Tunneling expert

- Daily geotechnical report
  - Geotechnical Engineer
  - Engineering Geologist
  - Geotechnical Monitoring

- Monthly geotech. meeting
Geotechnical safety management plan – Organization plan and reporting – “ABNORMAL BEHAVIOR”

- Authorities
- Media
- Relatives
- Relief org.
- …

Owner / Client
- Project manager
- Site manager

Tunneling expert

Event-driven geotech. meeting

Site Supervision
- Head of site supervision

Contractor
- Site manager

Designer/ Experts

Geotechnical Engineer
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geotechnical reports
Many thanks for your attention!