Observational method

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1 Introduction and Definitions

The observational method was introduced by Terzaghi and Peck (1948) and first described in detail by Peck (1969). The observational method can be an inherent element for construction in geotechnical engineering and comprises the complete process including design, construction control and monitoring. The idea is to apply appropriate and predefined measures or modifications to the construction according to the observations. The final aim is to achieve safe, environmental friendly and economical solutions. This can be achieved by reduction of epistemic uncertainty in the relevant parameters. The observational method can be combined with stochastic approaches, for instance the Bayesian approach (Stille & Holmberg, 2008, Stille & Holmberg, 2010; Spross & Johansson, 2017)

The observational method is defined in EC-7 (Eurocode) and DIN 1054 (German standard) and can be subdivided into 4 tasks:

- Definition of limit values and prediction of behaviour for planned geotechnical construction; development of an plan of measures in case of critical situations
- Observations and measurements in respect to the ground (rock mass) behaviour during the construction
- Comparison between prediction and in-situ observations and measurement results
- Take measures to avoid critical situations or optimize construction

The observational method is an active procedure, which leads to a modification of the design based on additional information obtained during the construction process. The final construction obtained applying the observational method has to meet all requirements in respect to stability, safety and serviceability, but will be very likely more economical compared to the classical approach.

The observational approach must be based on a clear definition of critical problems, potential failure mechanisms and corresponding countermeasures. It should not be misinterpreted just as a kind of trial-and-error procedure during the construction phase. Instead it needs a detailed planning and dimensioning in advance incorporating all the uncertainties.

2 Observational method according to EC-7

In EC-7 (EN 1997-1:2014), the requirements of the observational method are defined as follows:

(1) When prediction of geotechnical behaviour is difficult, it can be appropriate to apply the approach known as 'the observational method' in which the design is reviewed during construction.

(2) **P**: The following requirements shall be met before construction is started:

a) Acceptable limits of behaviour shall be established;

b) The range of possible behaviour shall be assessed and it shall be shown that there is an acceptable probability that the actual behaviour will be within the acceptable limits;

c) A plan of monitoring shall be devised, which will reveal whether the actual behaviour lies within the acceptable limits. The monitoring shall make this clear at a sufficiently early stage, and with sufficiently short intervals to allow contingency actions to be undertaken successfully;

d) The response time of instruments and the procedures for analysing the results shall be sufficiently rapid in relation to the possible evolution of the system;

e) A plan of contingency actions shall be devised, which may be adopted if the monitoring reveals behaviour outside acceptable limits.

(3) **P**: During construction, the monitoring shall be carried out as planned.

(4) **P**: The results of the monitoring shall be assessed at appropriate stages and the planned contingency actions shall be put into operation if the limits of behaviour are exceeded.

(5) **P** Monitoring equipment shall either be replaced or extended if it fails to supply reliable data of appropriate type or in sufficient quantity.

The principles marked with "**P**" must not be violated.

3 Example: tunnelling

The observational method can be considered as integral part of the NATM (New Austrian Tunnelling Method), especially if we integrate the first step of the observational method: definition of limit values incl. acceptable ranges of values and prediction of behaviour for planned geotechnical construction as well as development of a plan of measures in case of critical situations. A complete portfolio on countermeasures should be available to react flexible to any kind of critical situation.

During the tunnel construction the overall behaviour is monitored. This comprise for instance damage processes at the tunnel face or walls, water inflow, fracture development, failure of support elements etc. In addition, deformations, strains and stresses are measured at certain locations. Typical measurements are: convergence measurements, extensometer and inclinometer measurements, laser scanning or video-inspection, stress/pressure measurements inside the rock mass, the lining or the corresponding interface as well as in anchors.

If measurements reach critical values or observations arises critical, some of the already predefined countermeasures will be undertaken. Such measures could be: increase of liner thickness, application of additional and/or stronger anchors, use of different anchor schemes, change of excavation scheme, use of additional support at the tunnel face etc.

Interesting applications of the observational method in tunnelling are given for example by Bjureland et al. (2017), Stille & Holmberg (2010) or Kovari & Lunardi (2000).

Fig. 1 and Fig. 2 illustrate how the observational method can be integrated into the construction process in rock engineering and especially in tunnelling (NATM).

The problem of predictions in rock engineering is, that uncertainties are quite high and can be limited only to some extend even by considerable effort. These uncertainties are mainly based on:

- Uncertainty in rock mass quality incl. hydro-mechanical interaction of rock mass
- Uncertainty in in-situ rock stresses
- Quality and function of support measures
- Interaction between rock mass and support

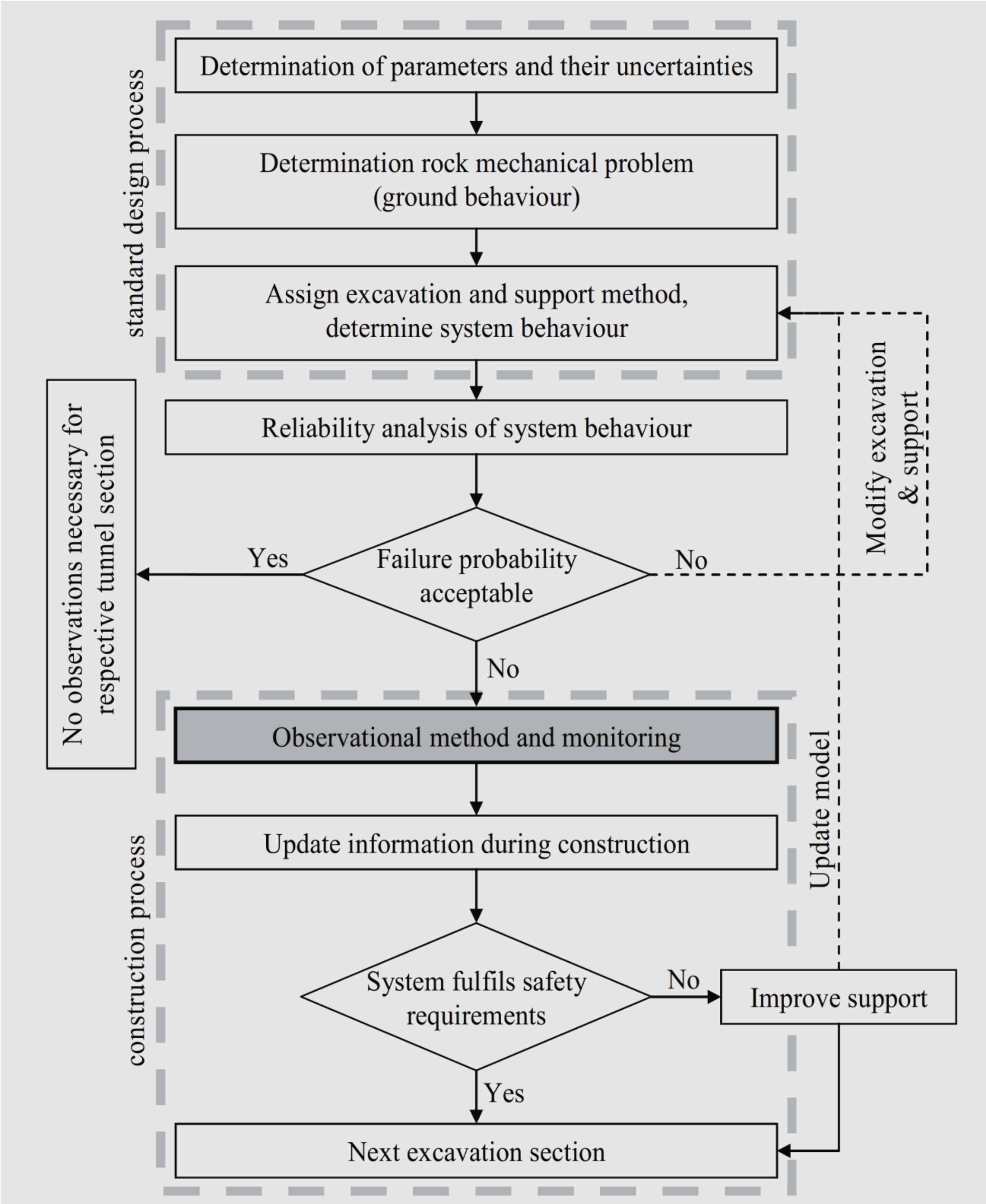

Fig. 1: Observational method as integral part of the design and construction process (Stille & Holmberg, 2010)

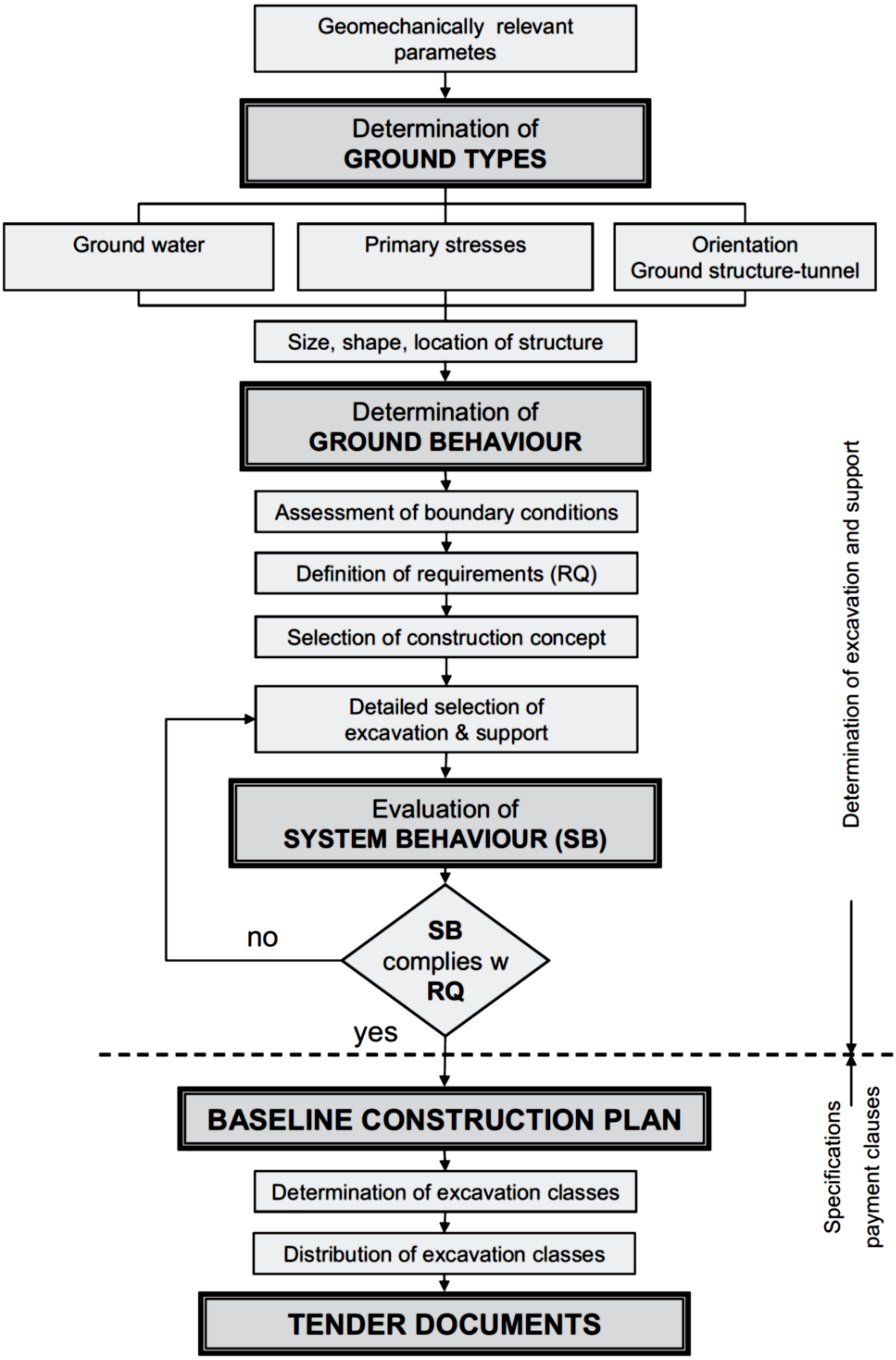

Fig. 2: Flowchart of geotechnical design procedure for underground construction work using with cyclic advance (after OeGG, 2001)

4 Example: rock pillar

Spross & Johansson (2017) compared conventional and observational method using a simple example: design of a pillar (see Fig. 3 and Tab. 1). The probability of pillar failure was determined to be 0.0046. The required safety was set to 0.001. Therefore – although the failure probability is quite low - the application of 4 anchors is necessary in case of a conventional design to meet the required safety demand.

Fig. 3 compares both procedures in terms of decision trees assuming two different final situations: failure or stable situation. The observational method bifurcates into the preliminary design (no anchors) and the modified design (with anchors). Tab. 1 summarizes the corresponding costs.

Tab. 1 documents:

- Failure would create huge costs (in any case slightly above 5000 monetary units)
- Observational method with modified design would result in slightly higher costs compared to conventional design (220 vs. 150 monetary units)
- Observational method with preliminary design would result in significantly lower costs compared to conventional design (50 vs. 150 monetary units)

If one takes into consideration, that probability of failure in case of pillar without anchors is quite low, the observational method has the potential to save a lot of money (also time, labour and material).

One should also bear in mind, that the modified design could include more options, like for instance use of less number of anchors and/or different type of anchors. This could lead to cost reduction, so that the modified design inside the observational method could even lead to lower costs than the conventional approach.

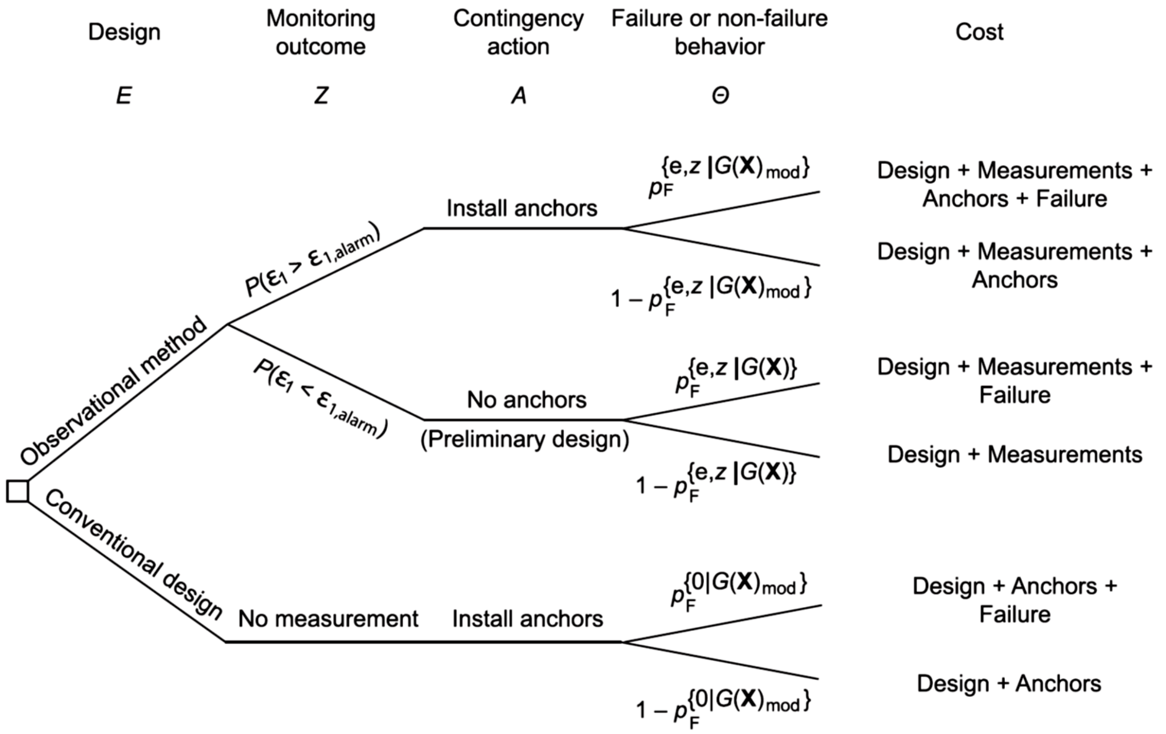

Fig. 3: Decision tree for conventional design and observational method (Spross & Johansson, 2017)

Tab. 1: Cost balance [monetary units] for rock pillar according to Fig. 3: conventional design vs. observational method (Spross & Johansson, 2017)

Type of design / procedure	Construction costs	Advanced measurement costs	Structural failure costs	Total costs
Conventional design (successful)	150	0	0	150
Conventional design (failure)	150	0	5000	5150
Observ. method preliminary design (successful)	30	20	0	50
Observ. method preliminary design (failure)	30	20	5000	5050
Observ. method modified design (successful)	200	20	0	220
Observ. method modified design (failure)	200	20	5000	5220

5 References

Bjureland, W. et al. (2017): Reliability aspects of rock tunnel design with the observational method, *Int. J. Rock Mech. Min. Sci*., 98: 102-110

Kovari, K. & Lunardi, P. (2000): On the observational method in tunneling, *Proc. GeoEng-2000*, 692-707

OeGG (2001): Richtlinie für geomechanische Planung von Untertagebauarbeiten mit zyklischem Vortrieb, Österreichische Gesellschaft für Geomechanik, Salzburg.

Peck, R.B. (1969): Advantages and limitations of the observational method in applied soil mechanics, *Geotechnique*, 19: 171-187

Spross, J. & Johansson, F. (2017): When is the observational method in geotechnical engineering favourable ?, *Structural safety*, 66: 17-26

Stille, H & Holmberg, M. (2008): Observational method in rock engineering, *Proc. ARMS-5*, 157-166

Stille, H. & Holmberg, M. (2010): Examples of applications of observational method in tunneling, *Geomechanics & Tunneling*, 3(1): 77-82

Terzaghi, K. & Peck, R.B. (1948): Soil mechanics in engineering practice, John Wiley & Sons, New York