Suggestion for a documentation of unexpected standstills in TBM-tunnelling

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ABSTRACT: Currently there is no uniform and consistent documentation of unexpected standstills available, which can be applied during the excavation of tunnels with tunnel boring machines (TBM). Such a documentation and evaluation would be helpful for the estimation of risks, costs and the advance rate for future tunnels excavated with a TBM. An approach for a documentation of unexpected standstills of hard rock tunnel boring machines, such as open gripper TBM, single shield TBM and double shield TBM, was developed at Graz University of Technology. This paper shows the results as well as the benefits of a detailed and continuous event documentation during tunnel excavation. The new approach can be taken as a basis for future documentation of unexpected standstills in TBM tunnelling.

1 INTRODUCTION

Nowadays large infrastructure projects with long tunnels, such as the Semmering base tunnel or the Brenner base tunnel in Austria, are in planning state or under construction. The length of such tunnels as well as the advantage of a fast excavation in favourable rock mass conditions make the use of a tunnel boring machine more and more important.. As for conventionally excavated tunnels, an excavation with a tunnel boring machine demands a detailed estimation of costs, risks, advance rates and construction time in advance, too. Boundary conditions have to be identified as exactly as possible in order to choose the most suitable machine type. Therefore, a detailed and continuous documentation of unexpected standstills of the tunnel boring machine applied during excavation would provide a proper basis for the design of future TBM driven tunnels. The documentation needs to be done contemporary. Reasons for standstills must be evaluated and interpreted. In addition to the documentation of the standstill reason, implemented measures to resume excavation again, have to be documented. Figure 1 shows a flow chart of such a documentation and the use of gained experience for future projects.

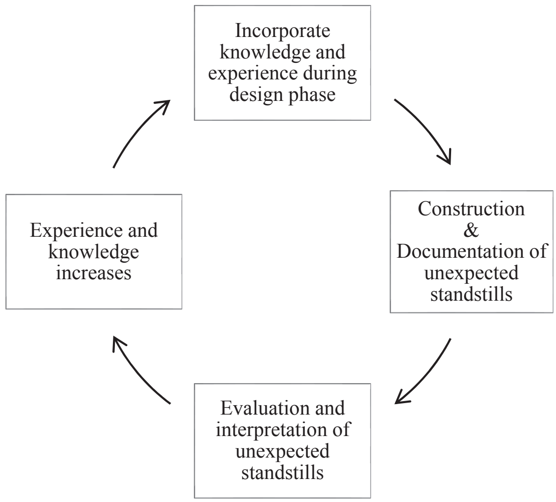

Figure 1. Flow chart of knowledge and experience transfer.

1.1 Application

The documentation of unexpected standstills described in this paper was primary developed for hard rock tunnel boring machines, such as open gripper TBMs (Gripper-TBM), single shield TBMs (TBM-S) and double shield TBMs (DSM). For the documentation of standstills of other machine types, such as EPB-shield or mixed shield, the proposed approach has to be adapted.

2 SUGGESTION FOR DOCUMENTATION

A questionnaire for the assessment of standstills of TBMs installed at infrastructure projects, which are already completed, was developed by Hofer (2014). Furthermore, a spreadsheet based on this questionnaire was established for standstills of TBMs installed at ongoing projects. Herein, daily site reports represent the source of information. All processes of construction over a certain period including unexpected delays are documented in site reports. Based on available site reports Hofer (2014) configured the suggestion for the documentation of unexpected standstills of hard rock tunnel boring machines. The following sections describe the data, which is required in order to develop a proper standstill report.

2.1 General information

In a first step, general information of the project must be determined:

- Geological conditions along the tunnel alignment / in the project area
- Machine type (open gripper TBM, single shield TBM or double shield TBM)
- Tunnel diameter and length of the tunnel (see Table 1 and Table 2)
- Duration of excavation (days of construction)
- Method of site supply and disposal
- Information about maintenance shifts and planned standstills

This project specific information is required to classify projects, to make projects comparable and to allow the identification for example of potential correlations between geological conditions in the project area and unexpected standstills. Repetitive documentation and evaluation for several projects results on the one hand in an increase of experience and on the other hand, in an increase of data, which can be analyzed statistically. Both can be serve as a decisive argument for the choice of e.g. the appropriate excavation method (conventional or continuous) or the most suitable machine type.

For a better comparability of different projects, categories for the tunnel diameter, the length of the tunnel and the maximum overburden were introduced (Table 1, Table 2 and Table 3).

Table 1. Categories for the tunnel diameter.

Tunnel diameter	Category
0 – 4,000 mm	D1
4,000 – 8,000 mm	D2
8,000 – 12,000 mm	D3
12,000 – 14,000 mm	D4
> 14,000 mm	D5

Table 2. Categories for the length of the tunnel.

Tunnel length	Category
0 – 4,000 m	L1
4,000 – 10,000 m	L2
10,000 – 16,000 m	L3
16,000 – 12,000 m	L4
> 20,000 m	L5

Table 3. Categories for the maximum overburden.

Maximum overburden	Category
0 – 20 m	O1
20 – 200 m	O2
200 – 1,000 m	O3
1,000 – 2,000 m	O4
> 2,000 m	O5

Detailed information on site supply and disposal are also important for the comparison of different projects. For example, site supply and disposal can be fulfilled by rail or crafts, which in turn can result in completely different types of standstills.

Specifications of the maintenance shift, such as fixed hours per day or flexible shifts, planned delays (e.g. holidays) etc. should also be documented.

2.2 *Categorization of standstills*

Standstills of excavations with a tunnel boring machine are divided in system related (planned) and random (unplanned / unexpected) standstills (Türtscher 2011). Maintenance shifts, extension of supply lines or tail tracks, holidays etc. can be categorized as planned standstills. Unexpected delays in tunnelling are assigned to three main categories (ground, technique and others) and respective sub-categories as shown in Figure 2 (Hofer 2014).

For each event, which caused a standstill of the tunnel boring machine, chainage dependent boundary conditions must be noted. Boundary conditions can be for example the geological and geotechnical conditions, and subsequently the predominant ground behavior after the guidelines issued by the Austrian Society for Geomechanics (ÖGG 2010, 2013), in case of a standstill dedicated to the main category "Ground". Sub-categories (e.g. human error, material fatigue) can be introduced as needed.

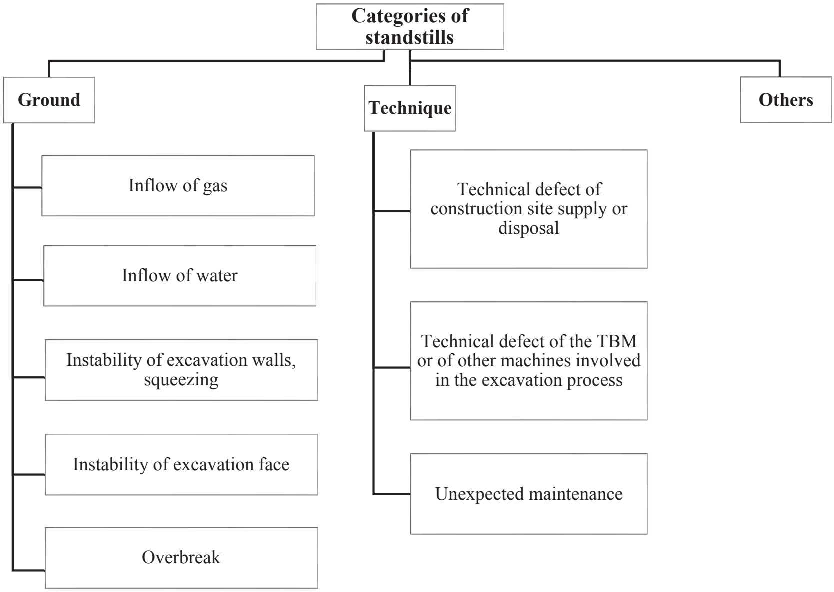

Figure 2. Categories of standstills.

3 EVALUATION OF SELECTED PROJECTS

By means of the suggestion for documentation, the unexpected standstills of seven projects have been evaluated and the results are presented below. Table 4 shows the general information of the projects.

Table 4. Overview of the general information of the evaluated projects.

Tunnel	Length (cf. Table 2)	Machine type	Bore diameter (cf. Table 1)	Maximum overburden (cf. Table 3)
1	L1	TBM-S	D4	O2
2	L1	TBM-S	D4	O2
3	L1	TBM-S	D4	O2
4	L2	DSM	D2	O3
5	L2	DSM	D2	O4
6	L1	DSM	D3	O3
7	L1	DSM	D3	O3

For all seven projects, the basis of data evaluation was different. Therefore, a straight comparison of the projects was not possible. Tunnel 1 to Tunnel 5 are completed, whereas Tunnel 6 and Tunnel 7 are still under construction. In general, the documentation of unexpected standstills should be made contemporary on basis of the daily site reports. Figure 3 shows a summary of the unexpected standstills at all seven projects. It has to be mentioned that planned maintenance shifts for Tunnel 1, Tunnel 2 and Tunnel 3 are assigned to the category “others”. For all other projects, maintenance is considered in “excavation” (excavation period).

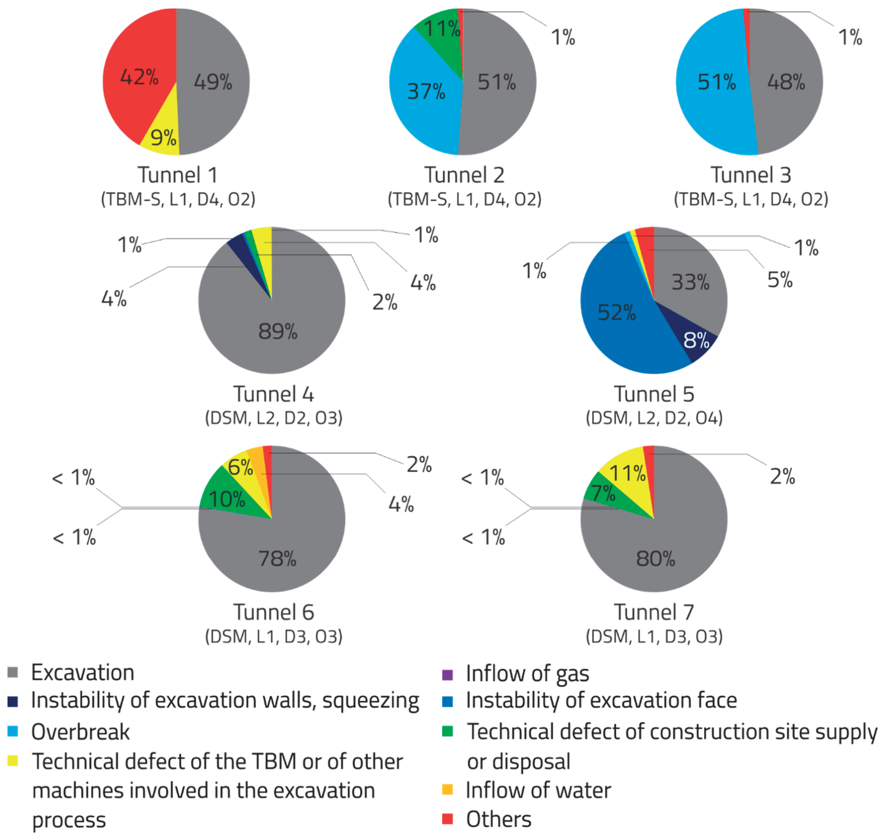

Figure 3. Evaluation of the unexpected standstills of seven projects (maintenance shifts: for Tunnel 1-3 included in “Others”; for Tunnel 4-7 included in “Excavation”).

For the evaluation of the unexpected standstills at Tunnel 6 and Tunnel 7, the site reports were analyzed. Based on these reports, the documentation template was extended and adapted. As both, Tunnel 6 and Tunnel 7 are situated in similar geological and geotechnical conditions, and applied site supply and disposal methods are identical, a detailed comparison of both projects is possible. Because Tunnel 6 and Tunnel 7 were under construction while the presented suggestion for documentation was developed, a length of about 3,000 m was considered for evaluation. Figure 4 shows the detailed evaluation results of the unexpected standstills at Tunnel 6 and Tunnel 7. All standstills have been assigned to the categories defined in Figure 2.

4 CONCLUSION

A continuous documentation of unexpected standstills in TBM-tunnelling provides a reliable and helpful source of information for the design of future projects. The standstills and their causes have to be recorded simultaneously with the geological, geotechnical documentation, and the machine data. If the approach for the documentation of unexpected standstills is exercised at several projects, the results can be summarized in a database. For a general conclusion regarding reasons for standstills of TBMs being prevalent, more projects have to be evaluated, included in the database, and analyzed statistically (probability distribution, correlations etc.).

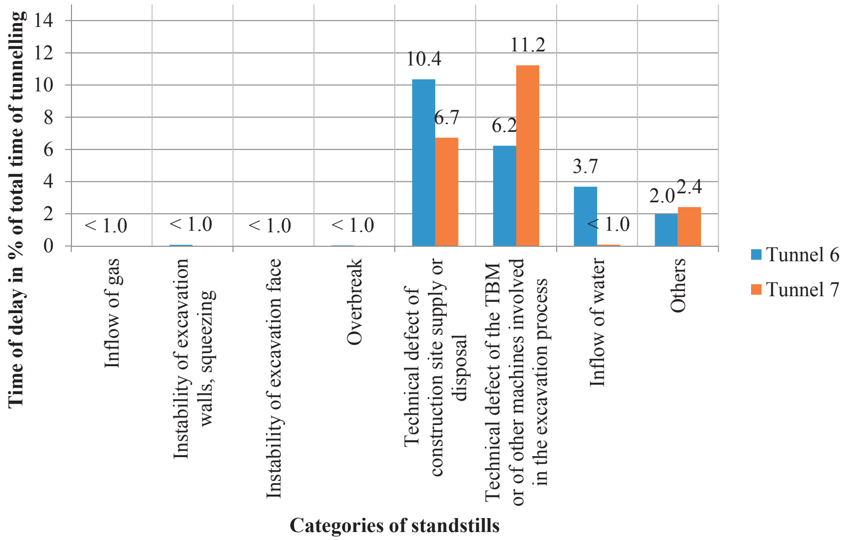

Figure 4. Comparison of unexpected standstills at Tunnel 6 (L1, DSM, D3, O3) and Tunnel 7 (L1, DSM, D3, O3).

Even though just a few projects have been analyzed, following can be noted:

1. The available records of standstills and the level of documentation detail have been quite different at each project, which makes a comparison even more difficult. Hence, the documentation procedure should be generalized and provided by the owner.
2. All types of reasons for a standstill of a tunnel boring machine defined in Figure 2 could be encountered at the seven projects.
3. However, for tunnels excavated with a TBM-S, "overbreak", "Technical defect of construction site supply or disposal" and "Technical defect of the TBM or of other machines involved in the excavation process" are the predominant reasons for a standstill (see Figure 4, Tunnel 1-3). In case of tunnels excavated with a DSM, in addition to the reasons mentioned for TBM-S driven tunnels, instability of the underground structure ("Instability of excavation walls, squeezing"; "Instability of excavation face") causes major problems, too.

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