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Engineering inspection and supervision of tunnels and underground stations of urban metro systems

Inspection et surveillance des tunnels et stations de métro souterraines

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ABSTRACT: According to the general standards and regulations civil engineering structures like bridges are supposed to be inspected and supervised regularly regarding stability, transport safety and durability. Unfortunately there are no national or international technical standards for tunnels and underground railway structures. Based on existing general standards and regulations for civil engineering structures a new concept for engineering inspection and supervision of tunnels and underground structures of urban metro systems has been defined by the Institute and Laboratory of Geotechnics of Technische Universität Darmstadt. The defined modalities and continuous procedures guarantee a sustainable preservation of the underground structures by early identification of insufficiencies and defects. The developed concept is applied to the engineering inspection and supervision of the tunnels and underground stations of the urban metro system of Frankfurt am Main, Germany. The concept can be applied to other urban metro systems anywhere in the world if the boundary conditions like construction type, age, load impact and soil and groundwater conditions are adjusted.

Resume: Selon la loi et les normes générales existantes, les structures de génie civil comme les ponts doivent être régulièrement inspectées et surveillées du point de vue de leur stabilité, leur sécurité de transport et leur durabilité. Il n'existe malheureusement pas de normes techniques pour les tunnels et les structures de transports souterrains. Un nouveau concept d'inspection et de surveillance des tunnels et stations de métro souterraines a été mis en place par l'Institut et le Laboratoire de Géotechnique de la Technische Universität Darmstadt, en se basant sur des normes et lois générales existantes en génie civil. Les modalités et procédures régulières définies dans ce projet assurent une protection durable des infrastructures souterraines grâce à l'identification précoce de défauts et d'insuffisances. Ce concept est mis en application pour l'inspection et de la surveillance des tunnels et stations de métro souterraines à Francfort, en Allemagne. Il peut être également appliqué à n'importe quel autre système de métros souterrains en adaptant les conditions limites telles que le type et l'âge de la construction, l'impact de charge, les propriétés du sol et de la nappe phréatique.

KEYWORDS: Inspection, supervision, urban metro system, tunnels, underground stations.

1 THEORETICAL BASICS

According to the general standards and regulations all civil engineering structures like bridges, retaining walls and tunnels have to be inspected and supervised regarding stability, traffic safety and durability. This obtains for tunnels and underground stations of urban metro systems as well. The basis for qualified engineering inspection and supervision of all civil engineering structures are a lot of national regulations and standards, for example (Schweizerischer Ingenieur- und Architektenverein 1997, Deutsches Institut für Normung 1999, Verband Deutscher Verkehrsunternehmen 2005, Schweizer Bundesamt für Straßen 2005, Bundesministerium für Verkehr 2007a and 2007b, DB Netz AG 2011). There are no national or international standards or regulations regarding the engineering inspection and supervision of urban metro systems.

In the last decades enormous financial resources were spend for planning and construction of underground engineering structures of public infrastructures. These investments are only maintainable if the structures have a long service time. Regarding the sustainability of the structures the engineering inspection and supervision has a growing importance (Morawietz 1992, Haack and Schäfer 2009).

The objective of the continuous inspection and supervision is the economic supply and maintenance of the structures. This

means a long-term indemnification of stability, traffic safety and durability.

The 3 aspects stability, traffic safety and durability are defined as follows:

- Stability means the absorption of regular loads by the structure
- traffic safety means the riskless use of the structure
- durability means a long as possible use of the structure under consideration of stability and traffic safety

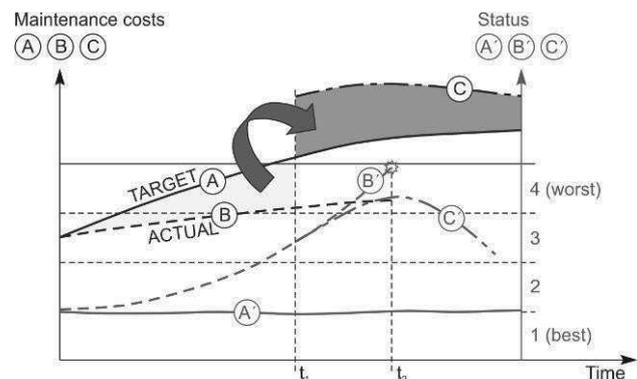


Figure 1. Time related connection between maintenance cost and status of structures (Wicke at al. 2001).

fire) or are necessary after standard or main inspections. Special inspections (S) do not replace the regular inspections (E) and (H).

The supervision (B) takes place twice a year and consists of a quick ascent. The underground supervision (B) is done on the traffic level of the structures and is not applied in years of standard or main inspections (E, H). The supervision (B) on the surface has to detect the construction works that may have an influence on the stability, traffic safety and durability of the underground structures. The supervision (B) on the surface is independent to all inspections and supervisions in the underground.

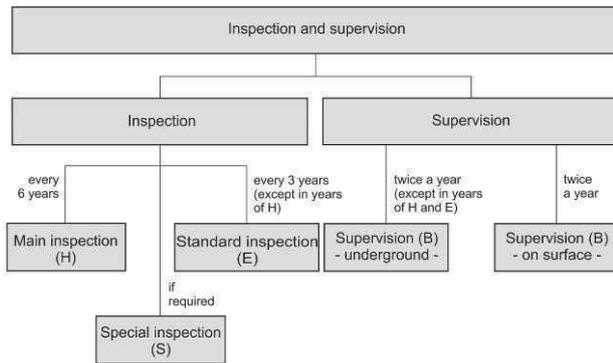


Figure 3. Engineering inspection and supervision of tunnels and underground stations of the urban metro system in Frankfurt am Main.

Table 2 shows an example of the schedule of the modalities and procedures of engineering inspection and supervision.

Table 2. Example of the schedule of the modalities and procedures of engineering inspection and supervision.

Test section	Year				
	2011	2012	2013	2014	2015
Test section A	H 2 x B ²	2 x B ¹ 2 x B ²	2 x B ¹ 2 x B ²	E 2 x B ²	2 x B ¹ 2 x B ²
Test section B	E 2 x B ²	2 x B ¹ 2 x B ²	2 x B ¹ 2 x B ²	H 2 x B ²	2 x B ¹ 2 x B ²
Test section C	2 x B ¹ 2 x B ²	H 2 x B ²	2 x B ¹ 2 x B ²	2 x B ¹ 2 x B ²	E 2 x B ²
Test section D	2 x B ¹ 2 x B ²	E 2 x B ²	2 x B ¹ 2 x B ²	2 x B ¹ 2 x B ²	H 2 x B ²

H - Main inspection
E - Standard inspection
B¹ - Supervision (underground)
B² - Supervision (on surface)
S - Special inspection (if required)

3 APPLICATION IN ENGINEERING PRACTICE

The staff that is responsible for the engineering inspection and supervision has to regard the stability, traffic safety and the durability of the tunnels and underground stations. Insufficiencies and defects are documented according RI-EBW-PRÜF (Bundesministerium für Verkehr 2007). An insufficiency is the deviance of the planned status of a structure or the applied regulations. An insufficiency may have an effect on the stability, traffic safety and/or durability. A defect is a weakening or a damage of a structure that has definitively an effect on the stability, traffic safety and/or durability.

In the case of a main inspection (Fig. 4) and if necessary in cases of a special inspection (S) an evaluation of the status of the structure is made regarding stability, traffic safety and durability.

According to RI-EBW-PRÜF an extensive composition of possible insufficiencies and defects was created by the TU Darmstadt. This composition has benchmarks for the evaluation of the status of a structure. The evaluation of an insufficiency or a defect with 0 means that there is no effect on the stability, traffic safety and durability. An evaluation of an insufficiency or a defect with 4 means that the stability, traffic safety and/or the durability is not given.

The durability is the most important aspect because it affects the stability and the traffic safety. The evaluation of an insufficiency or a defect regarding the durability has always minimum the same number as regarding the stability and the traffic safety.



Figure 4. Main inspection in a tunnel.

The evaluation of the insufficiencies and defects lead to a status grade for each tunnel section resp. underground station. A status of 1.0 to 1.4 means that stability, traffic safety and durability of the tunnel section or underground station are given. A status grade of 3.5 to 4.0 means that stability, traffic safety and durability of the tunnel section or underground station are not given. The determination of a status grade of a structure is shown in Figure 5.

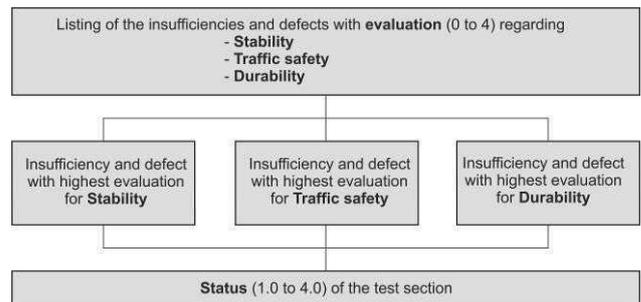


Figure 5. Determination of a status grade of a tunnel section or an underground station.

The determination of a status grade of a structure is important for the maintenance actions. Connected to the status grade the time periods of the maintenance actions have to be defined. The actions have to be carried out shortly (less than 6 month), in the medium term (less than 3 years) or in the long term (less than 6 years). In very dangerous cases immediate actions have to be carried out.

The results of the engineering inspection and supervision are the basis for the planning of the maintenance actions and the

necessary maintenance investments (Table 3). So it is possible to combine maintenance aspects with economic aspects.

Due to the experiences made with a lot of construction projects on the surface the supervision (B) on the surface above the underground structures was added to the supervision procedures. For example the deconstruction of an up to 14 stories high-rise building released the soil and the underground structure under the project area. Due to the unloading of the soil the tunnels and the underground station got an uplift of about 2 cm (Katzenbach et al. 2011).

Nearly all modalities and continuous procedures of the engineering inspection and supervision are carried out during the operation of the urban metro system. The safety of the staff has to be guaranteed.

Table 3. Example of status grades of tunnel sections.

Test section	Year				
	2011	2017	2023	2029	2035
Test section A	1.8	1.8	2.1	2.8	3.0
Test section B	1.3	1.3	1.5	1.9	2.2
Test section C	2.4	2.8	3.1	3.5	2.9
Test section D	1.9	2.1	2.2	2.4	2.6
1.0 - 1.4 very good condition of the structure 1.5 - 1.9 good condition of the structure 2.0 - 2.4 satisfactory condition of the structure 2.5 - 2.9 sufficient condition of the structure 3.0 - 3.4 nearly insufficient condition of the structure 3.5 - 4.0 insufficient condition of the structure					

4 CONCLUSIONS

On the basis of standards and regulations for engineering inspection and supervision of different civil engineering structures the TU Darmstadt developed a new concept for tunnels and underground stations of urban metro systems for a sustainable supply and maintenance of these structures. The concept defines the modalities and the continuous procedures of the inspections and the supervision and gives the possibility for the evaluation of insufficiencies and defects of the structures.

The particularity of the engineering inspection and supervision of underground structures results from 2 aspects. On one hand the structure is only visible from the inner face of the structure. On the other hand the operating crews of the metro trains are one part of the continuously supervision with short time for detection of insufficiencies and defects.

It is possible to transfer the developed concept to the urban metro systems of other cities by adapting the boundary conditions.

The developed concept will be adjusted to the following aspects:

- experiences made in the next years
- increasing age of the structures
- new methods for inspection and supervision of the structures

Due to the fact that there are no standards and regulations of engineering inspection and supervision of tunnels and underground stations of urban metro systems an International regulation should be prepared.

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