ADVANCES IN THE DIGITAL DOCUMENTATION OF RAILWAY TUNNEL INSPECTION

[1]Matthias J. Rebhan, [2]Stefan S. Grubinger, [2]Andreas Schüppel, [3]Simona Deutinger, [3]Gernot Schwarzenberger
[1]Graz University of Technology, Institute of Soil Mechanics, Foundation Engineering and Computational Geotechnics, AT
[2]recordIT GmbH, AT
[3]ÖBB Infrastruktur AG, AT

DOI 10.3217/978-3-85125-996-4-19 (CC BY-NC 4.0)

ABSTRACT

Like other infrastructure, railway tunnels require inspection to ensure their safety and to detect damages at an early stage, representing a major challenge for those involved. Thus, in addition to the inspection, the tunnel down time can be a major disruption in operation. Under economic aspects, the inspection itself with all the subsequent work required is very time-consuming. In the area of rail networks, comprehensive preparations are necessary to be able to plan track barriers and bypass measures accordingly to minimise any undue influence on availability. This paper presents the results of an initial test phase of using a digital documentation solution in order to generate a rapid localisation and a corresponding time advantage when carrying out the inspection activities. By offering the use of a multitude of bases, a standardisation of damage patterns is carried out and a collaborative cooperation of multiple inspection personnel is possible. Depending on the data stock, digitised as-built models in the form of a plan, digital plan documents and existing or generated digital twins can be used. Thus, making it possible to locate the damages already in the course of the inspection and therefore enable a comprehensible documentation of the inspection activity and an automated generation of inspection reports.

In the course of a series of field tests along four tunnels of the Tauern Line of the Austrian Federal Railways, the digital procedure was validated in form of a pilot project. Within this paper the first results, together with the advantages of a digital inspection are presented.

Keywords: inspection, digital twin, digitalization, tunnel safety

1. RAILWAY TUNNEL INFRASTRUCTURE IN AUSTRIA

The entire route network of the Austrian Federal Railways has a length of 4,965 km with 1,032 stations and enables a saving of 4 million tonnes of CO_2 (for 2022) through rail transport [1] compared to transport by road. In addition to a large number of properties and tracks together with the railway stations, there are also a large number of civil engineering structures (assets) which are required for the construction and routing based on the topography and the alignment. In addition to bridges and retaining structures, there are also 254 tunnels [2] along the entire railway network. These have an average age of 45 years and a target service life of 141 years on average. A relatively high number of 150 tunnels and tunnel-like structures have already reached an age of 100 years or more, of which 63 tunnels are already more than 150 years old and date back to the intensive construction period around 1850. These include the tunnels along the Semmering line, which were recognised as a UNESCO World Heritage Site in 1998 [3]. Figure 1 shows the location of tunnels along the Austrian Federal Railways network. It can be seen that they are distributed across the entire railway network. However, it can also be clearly seen that tunnels (the blue dots in Figure 1) are more frequent in the Alpine areas of Austria as well as in the vicinity of major cities or transport hubs.

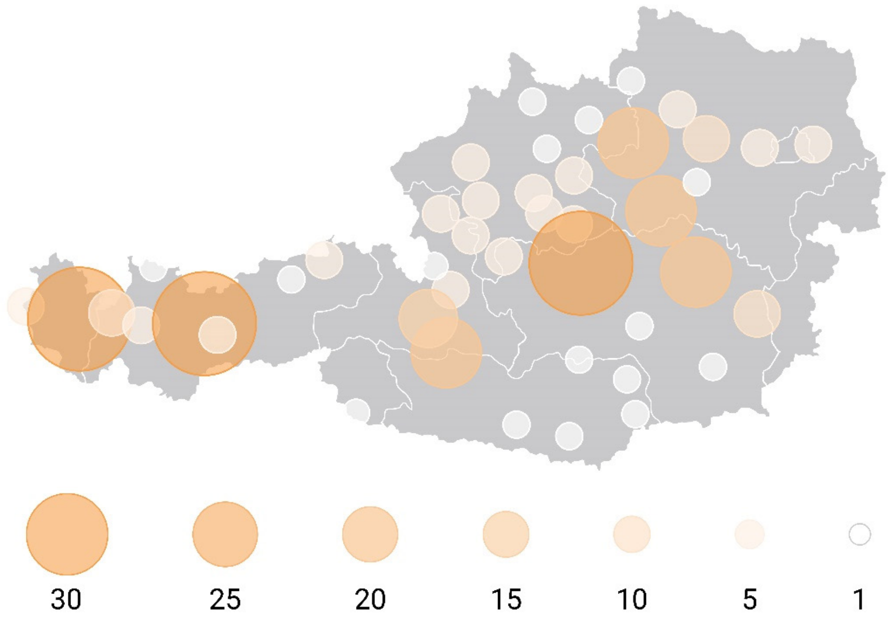

Figure 1: Tunnels along the Austrian railway network

Due to their position within the network, its linear extension and the lack of diversions and bypasses, tunnels have a significant influence on the availability of the route and thus to the operation of the railway, making them a key factor for a smooth operation.

2. STATE-OF-THE-ART IN INSPECTION OF RAILWAY TUNNELS, DAMAGES AND DAMAGE SYMPTOMS

The inspection of structures is a challenging, demanding, and highly responsible task for civil and geotechnical engineers. In general, a distinction is made between the inspection of buildings and industrial structures (object safety inspection according to the standard ÖNORM B 1300 [4] and ÖNORM B 1301 [5]) and civil engineering structures. The latter are regulated in the guidelines of the RVS 13.03 series – Quality Assurance for Structural Maintenance, Monitoring and Inspection of Engineering Structures. The focus lays generally on a visual inspection, which includes all relevant and non-relevant components and structural elements required for traffic safety. Inspection activities are carried out periodically and conclude with a report or assessment. This provides information on the state of preservation, defines further steps for maintenance and serves as the basis for subsequent inspection intervals.

2.1. State-of-the-art in inspection of civil-engineering structures focus on tunnels

Planning documents usually constitute the basis for every inspection activity, especially for civil-engineering structures. These form the basis for the scope of inspection and provide the necessary structural and safety-related information on a structure, which defines the tasks for the inspection personnel. Furthermore, these documents provide the basis for recording information of the inspection during the field work. Examples of this are damaged areas, image numbers, changes compared to preliminary inspections or changes in the state of preservation. Such documents are usually available digitally in the form of drawings (usually

*.dxf or *.dwg format), in PDF format, and even scans, as shown in Figure 2. However, there are also situations in which no documents of a tunnel are available. Therefore, these must be created in the course of the inspection or during its preparation, in order to enable the inspection activity and the generation of a report or an assessment result.

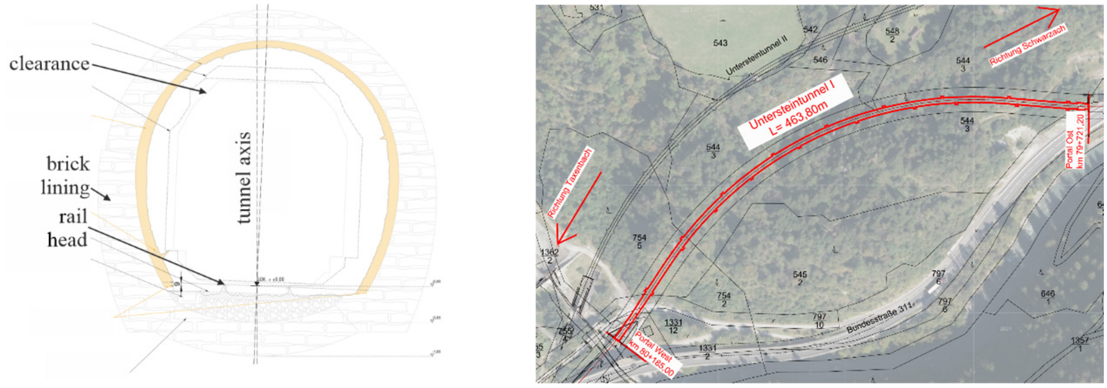

Figure 2: Example of an 2D plan as a basis for an inspection - cross-section (left) and longitudinal section (right)

In addition to a lack of documents, it must also be assumed that existing documents originate from the planning and design phase. Consequently, due to changes or construction and geological-related adjustments, such documentation only to a limited extent correspond to the actual structure. In particular in the case of geometry, it must be assumed that the documentation is neither complete nor conclusive.

2.2. Damages and damage symptoms

One of the main goals of a tunnel inspection is the recording of damage patterns and their comprehensive documentation in order to derive the state of preservation and, above all, to be able to determine their effects on the load-bearing capacity, serviceability and traffic safety.

Figure 3: Examples for damages of the lining of tunnel, top: damages on a masonry lining, bottom: cracks and crack patterns of a shotcrete lining

As shown in Figure 3, damage to the inner lining of the tunnel is usually recorded, documented and assessed during a visual inspection of the structure. In the case of tunnels in Austria, a distinction can be made between damage to masonry linings (Figure 3 top) and damage to concrete segments or a shotcrete lining (Figure 3 bottom).

3. DIGITAL INSPECTION SOLUTIONS

Digitalization is one of the main topics in research and development in the construction industry. Currently, the focus here is on new constructions and, above all, the integration of the BIM process in all project phases from planning to utilisation and maintenance. Only limited attention is currently being paid to the application of digitalisation measures to existing buildings and civil engineering structures. However, digital solutions for building inspection can bring a number of advantages here, which are of course associated with possible disadvantages. A brief summary of these is provided in Table 1.

Table 1: Advantages and disadvantages of digital solutions for tunnel inspection (overview)

Advantages	Disadvantages
Time saving	User reluctance
Reduced downtime and inspection effort	Modification of processes required
Data utilization for evaluation	Digital model of the structure required
Intuitive and self-explanatory usage	Missing usability
Integration into inspection databases	Ongoing standardisation required
Transfer of inspection results	
Multiple user applications	
Virtual inspection	

As Table 1 shows, a number of advantages can be generated through the digitalization of inspections, especially for civil engineering structures. The biggest and usually most decisive point is the saving potential in terms of on-site time. Time can for example be saved, by using an existing inspection documentation from previous tasks, which can generate a considerable advantage, especially when documenting damaged areas and defects. In addition to the monetary savings, this can result in shorter closure times (track barriers), especially when inspecting railway infrastructure due to the fact of missing bypass possibilities. This can result in a reduced need for total closures and an improvement in track availability. In addition, a software solution used on-site creates a standardised and less error-prone inspection, from which reports, a documentation and an assessment can be created with little effort. Furthermore, information and characteristic values as well as a periodical documentation can be further processed digitally. In addition, the current condition of a structure can be depicted more comprehensively using pictures, allowing a comparison between inspection periods.

In addition to these advantages, there are also disadvantages associated with a digitalization - or generally a change and adaptation of an existing process using digital solutions. On the one hand, these relate to usability and the utilisation of a digital solution by users. However, an appropriate approach (UX and UI design) can remedy this. On the other hand, the pervasive and sustainable use of digital solutions often requires adjustments to databases, data structures and standardisation in general. In Austria, there is currently a lack of specifications in the area of inspection regulations, relating to the use of digital processes for inspections.

One of the main advantages of digitalization from a practical point of view, as mentioned in Table 1, is the fact that several users can use the solution at the same time on the same project. In addition to time-saving, this leads to a possible division of tasks with regard to the expertise of the inspection personnel. It has also been shown that this results in a standardisation of processing - through consistent standardisation. Such an approach can also lead to a transfer of expertise - in the form of an exchange of experience. This is particularly the case with a periodic and recurring use of inspection documents and the data and information from inspections by different personnel or changing subcontractors for the inspection.

4. WORKFLOW FOR A DIGITAL INSPECTION AND EXAMPLES FROM A SERIES OF INITIAL FIELD TESTS

In addition to the advantages offered by digitalization, it is also important to adapt working methods and processes to the newly created possibilities in order to generate a corresponding increase in time-saving and quality improvement. Preparation remains essential, but the approach will take a different form. For the most part, the collection of inventory data will no longer be necessary and a stronger focus on existing issues and damages will be possible. However, it is not only the preparation that changes, the form of inspection also changes when digital solutions are used. For example, due to standardisation and the use of former inspection results, inspection personnel will receive a much stronger role as a controlling element. This results from the fact that a software-supported inspection already specifies or can specify defects or damages from former on-site inspections and thus can provide a framework for the documentation on-site whilst conducting the inspection. As an introduction to the workflow described in chapter 4.5, the respective basic principles are described below.

4.1. Master files and data preparation

Master data for structures is generally stored in a database after it has been entered once and is reused in identical form for every inspection. The already existing and standardised assessment bases also provide a basis for assessing and reporting that can be used and evaluated in the same way for subsequent inspections.

4.2. Drawings, sketches and other documents

Similar to the master data, planning bases are also implemented (normally) only once, which enables comparability and, in addition, usability of the information and data generated during subsequent inspections. This allows a "single point of truth" to be created for the inspection, making the digital inspection software a valid source of information for managing recurring inspections, but also for maintenance, refurbishment or adaptation. Examples of plan/drawing bases range from scans or photos, as shown in Figure 2, to the use of 3D models from terrestrial and mobile laser scanning images [6] or extracted from BIM models.

4.3. Annotate / Asses / Localise

Using a software, annotation (the addition of comments) and the allocation of facts can be carried out directly on-site using a pre-defined methodology. This means that the results can be compared with a certain degree of standardisation and the inspection personnel is able to select and allocate damages or information quickly. In addition, the ongoing experience of the inspection personnel - with regard to the increase in damage patterns and defects - can also be incorporated, resulting in a continuous improvement of the inspection quality.

4.4. Integration of results and findings

The integration of the collected and recorded information into databases can be largely automated. This eliminates the otherwise time-consuming task of transferring data and information and also offers the creation of more comprehensive reports.

4.5. Workflow for digital inspection of structures

The contents described in chapters 4.1 to 4.4 are part of a comprehensive process that is used both for non-digitalized inspection and for the application of a digital solution - albeit in partially different approaches. This is summarized in Figure 4 - with a focus on the digital implementation of the process.

Figure 4: Schematic workflow for an inspection and documentation of inspection works and damages with emphasis on the use of a digital inspection methodology (adapted from [6])

It can be seen that a database can be used as a central element, which must initially be filled with documents, data, and information and then supplemented by the damages, facts, and information as well as pictures of the inspection. Furthermore, this forms a cumulative possibility to derive maintenance measures as well as the necessary output options for reports and the safety assessment of the civil-engineering structure.

4.6. Inspection of railway tunnels using digital tools

As already mentioned, the usability and involvement of the inspection personnel in the development process of a digital solution for the inspection of tunnels is one of the decisive criteria for the success of a process as described in chapter 3. It is therefore necessary to include the practical on-site inspection processes in addition to pure software development. For this reason, comprehensive testing and subsequent improvement under real-life conditions is necessary. In the following, some constrains for the inspection of tunnels along the Austrian Federal Railways network are briefly described and the design criteria for a software solution developed for this task are briefly described.

Figure 5: Inspection and documentation of the lining of a tunnel

The images in Figure 5 show some circumstances that must be dealt with when inspecting tunnels for railway operation - and similarly for road operation. On the one hand, as shown in the left-hand image, climbing aids and transport equipment are required in order to be able to inspect the entire lining of the tunnel visually. In the case of railway tunnels, this is significantly influenced by the requirements for rail-bound solutions and the presence of overhead lines. On the other hand, a more comprehensive survey of the damaged areas, as shown in the picture on the left, must also be carried out as a rule in order to record and assess their effects on the load-bearing capacity and traffic suitability of the tunnel.

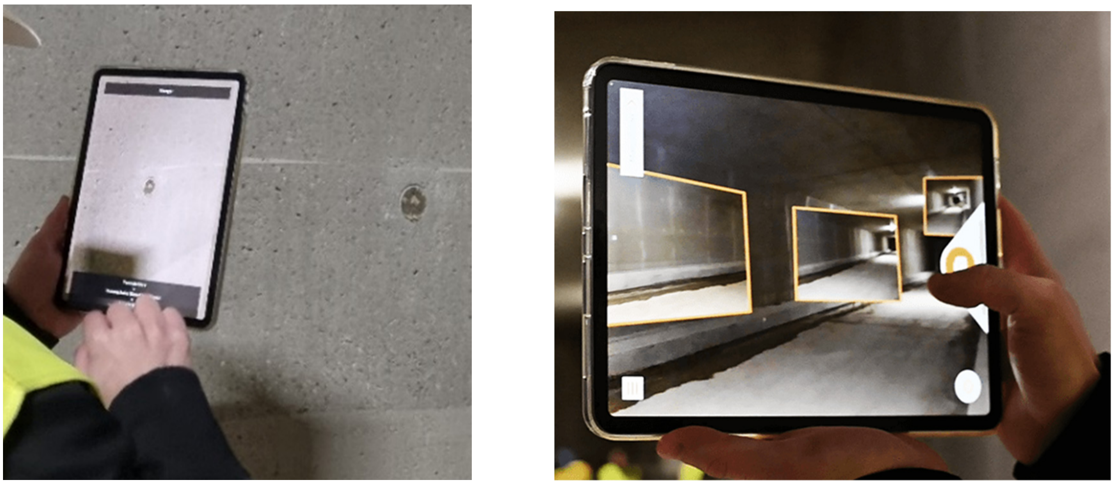

Figure 6: Examples of annotation and localisation of damage and defects, recording including annotation (left), integration of virtual reality to display existing inspection results (right)

Such requirements must be taken into account in software development and, above all, in UX (User Experience) and UI (User Interface) design. For example, as shown in Figure 6 on the left, selection boxes in the software must be of the appropriate size, so that they can be operated easily and under restricted handling conditions e.g. while wearing gloves. In addition, especially for recurring inspections, technologies such as virtual reality and augmented reality, as shown in Figure 6 on the right, can help to ensure that inspections can be carried out more quickly and thus reduce the duration of the inspection and the workload for the inspection personnel.

4.7. Use of digital inspection on other railway infrastructure

In addition to the tunnels mentioned in this article, the Austrian Federal Railways network also includes a large number of other structures to which the workflow described in this article can be applied. The aim here is to reduce the workload of the inspection personnel and, above all, to reduce track-barrier durations while maintaining a sufficient safety level.

Figure 7: Example of assets along the Austria railway lines, retaining structures (left), noise-protection constructions (centre), natural hazard-protection structures (right)

The examples in Figure 7 show a small selection of the existing structures on the Austrian railway network. Currently there are 8,363 retaining structures (Figure 7 left), 933 km of noise barriers (Figure 7 centre) and a vast number of protective structures against natural hazards (Figure 7 right), which must be inspected and assessed in accordance with the maintenance obligation (§19 Eisenbahngesetz 1957 i.e the railway legislation [7]).

5. SUMMARY AND CONCLUSION

This paper attempts to provide a brief insight into the requirements for the implementation of a software for the inspection in particular of civil structures of tunnels with focus on railway tunnels. In addition to the procedure and workflow for the implementation of digital processes, the integration of practice-relevant questions and handling are also shown. These were developed together with the future users of the Austrian Federal Railways and tested in a field study. From a technical point of view, the added value of a digital solution could be demonstrated, which lies primarily in the reduction of track downtimes and the reduction of workload for the inspection personnel. There is certainly potential for further development, for example to directly integrate digital models (e.g. 3D scans or BIM) and enable a more comprehensive utilization of data and information with regard to the maintenance strategy. In addition, such digital solutions can also be used to create a comprehensive data pool in order to drive forward solutions for image recognition and/or automatic information extraction from images. However, the aim behind such developments must always be to reduce downtimes of the infrastructure in order to ensure that the railway network can be operated economically and as smoothly as possible.

Furthermore, the realization of these developments showed that for a useful development of software solutions, it is necessary to ensure a close cooperation between the inspection personnel, the maintenance department and the software development to enable a comprehensive view and corresponding ensure the applicability of the solutions developed.

6. REFERENCES

[1] ÖBB (2022); Zahlen Daten Fakten ÖBB-Infrastruktur AG, ÖBB-Infrastruktur AG Stab Kommunikation, 2. Ausgabe / 1. Auflage.

[2] ÖBB (2022a); Netzzustandsbericht 2022, ÖBB-Infrastruktur AG GB Asset Management und Strategische Planung, Version 1.0.

[3] https://www.unesco.at/kultur/welterbe/unesco-welterbe-in-oesterreich/semmeringeisenbahn

[4] ÖNORM B 1300, 2018. Objektsicherheitsprüfungen für Wohngebäude - Regelmäßige Prüfroutinen im Rahmen von Sichtkontrollen und zerstörungsfreien Begutachtungen - Grundlagen und Checklisten. Austrian Standards. Wien.

[5] ÖNORM B 1301, 2016. Objektsicherheitsprüfungen für Nicht-Wohngebäude - Regelmäßige Prüfroutinen im Rahmen von Sichtkontrollen und Begutachtungen - Grundlagen und Checklisten. Austrian Standards. Wien.

[6] Grubinger et. al., 2023. Digitalisierungspotential der Prüfung geotechnischer Bauwerke, Beträge zum 37 Christian Veder Kolloquium, Technische Universität Graz, Institut für Bodenmechanik, Grundbau und Numerische Geotechnik, Graz.

[7] EisbG (1957). Bundesgesetz über Eisenbahnen, Schienenfahrzeuge auf Eisenbahnen und den Verkehr auf Eisenbahnen, BGBl. Nr. 60/1957, Fassung vom 02.12.2023.