Application of BIM Models for the Restoration and Renovation of Railway Tunnels

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The paper presents the findings obtained from a study into the use of 3D BIM technology for the restoration and renovation of railway tunnels.

Tunnelling • BIM • Restoration • Renovation • Railway

1 Introduction

Many of the tunnels that form part of the track infrastructure operated by Deutsche Bahn date back to the early years of the German railway system and were constructed more than 150 years ago. Some of these structures are now in urgent need of restoration and renovation. Digitisation now plays an increasingly important role in the construction work required for the renovation of railway tunnels and operations associated with route alignment and cross-sectional geometry, for example, can be optimised in the early stages of the project to take account of key factors such as scheduling, cost efficiency and sustainability. The existing structure and its foundation soils first have to be replicated in the BIM model in order to fully exploit the potential that BIM (Building Information Modeling) can offer to rail-tunnel restoration and renovation projects. Unfortunately this technique has not really been fully applied over the years and the experience that has been acquired in this area is therefore extremely limited.

A study was therefore undertaken to determine how the plans for a new tunnel could be modelled and integrated into an existing track structure as part of a BIM planning project for the restoration and renovation of railway tunnels. In order to ensure that the 3D modelling work employed for the study was developed using realistic parameters it was decided to apply data obtained from the Horchheimer Tunnel as the basis for the 3D model. This paper presents the findings that were obtained as part of the 3D modelling study.

2 Renovation of existing Rail Tunnels

The renovation of long-standing railway tunnels is a task that calls for a great deal of expertise. It also requires a real understanding of historical tunnel construction techniques so that just a few exploratory drillings will be sufficient to be able to recreate the existing structure. Fig. 1 shows by way of example the exploration boreholes and the structure of the transverse profile that was developed from them.

Renovating a tunnel requires an internal shell to be constructed within the existing cavity. The technical specifications for the regenerated tunnel are now essentially the same as those that apply in the case of a completely new tunnel, which means that in the course of the renovation work the clearance zone generally has to comply with current regulations and the existing cavity has to be widened accordingly.

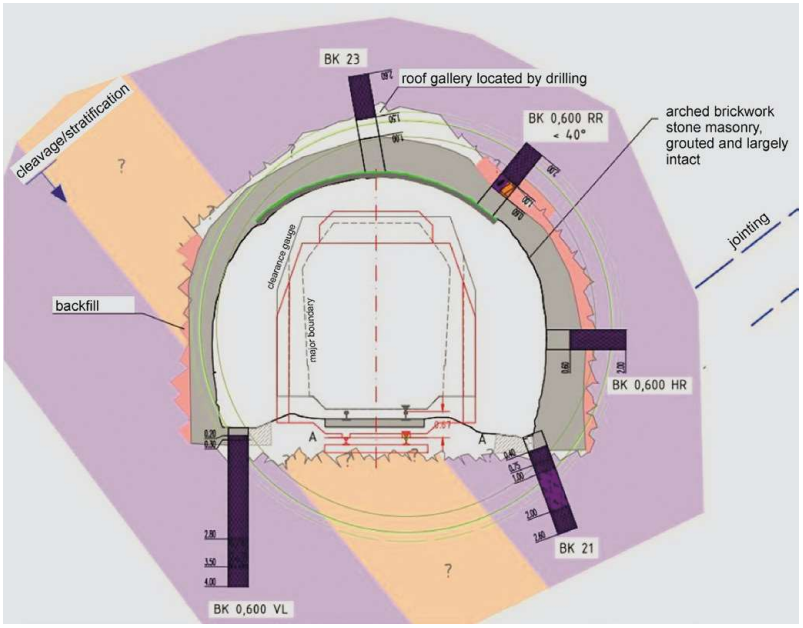


Fig. 1: Transverse profile showing existing structure with exploratory borings [1]

The excavation is undertaken in a longitudinal direction working section by section radially around the profile. The waste should ideally be removed in separate stages beginning with the track ballast and inner shell with backfill and ending with the contaminated sealant material (if present) and in situ rock. During the construction phase the exposed rock face is normally secured using the kind of support system frequently employed in the tunnelling industry, i. e. systematic rock-bolting and shotcrete. The new cast-in-situ concrete lining is then installed to provide a larger clearance area and a greater track spacing.

3 Data Basis and Software

As a first step the model was built up in such a way that the new tunnel structure could be planned within the

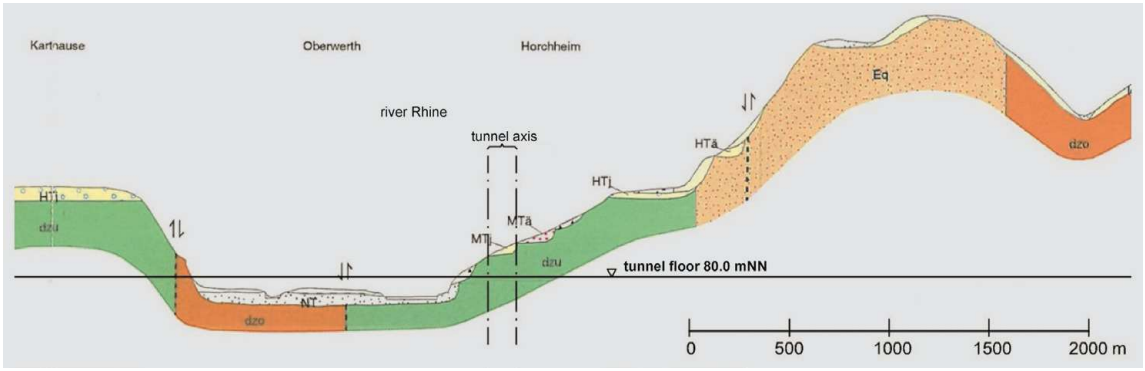


Fig. 2: Geological cross section at the north portal [1]

existing tunnel using conventional alignment software. In this way it was possible, within the model parameters, to develop and calculate the optimum balance between the excavation cubage of the tunnel roof and floor, the filling of the existing cavities and any particular waste disposal costs, and the occupational safety measures associated with the breakout of tar oil-based sealant material.

The details of the tunnel structure and strata make-up processed for the study were determined using:

- 3D laser scans obtained by overflying the area
- 3D laser scans of the tunnel face
- Core drillings and groundwater measuring points sited above ground
- Short-length core drillings arranged radially around the inside of the tunnel
- Probings and exploratory digs in and around the track area of the tunnel
- GPR in the tunnel floor and roof zone

Civil 3D and HoleBASE SI software was used for the modelling of the individual elements. Civil 3D is a structural design software that supports BIM working methods and offers particular advantages for infrastructure projects. HoleBASE SI is an add-on for Civil 3D that provides a drilling databank based on the results obtained from the soil investigations and laboratory tests, this serving to develop the 3D model of the existing structure and its foundations.

4 Tunnel Structure and geological Situation

The 576 m-long Horchheimer Tunnel, which came into service in 1902, is located between track points 0.484 km and 1.060 km on track no. 3031 between the Koblenz Pfaffendorf junction and the Koblenz Horchheimer Brücke junction. Under the terms of the safety obligations laid down in the General Railway Act (AEG) §4 the German Federal Railways are required to maintain the railway infrastructure in good working order. Regular structural surveys of the Horchheimer Tunnel reported a general deterioration in the integrity of the structure and as a result of these findings a general renovation was deemed necessary. The relevant planning approval process was completed in May 2021 and the main construction work has commenced in August of this year.

The track gradient rises in a north to south direction from about 78.8 to 80.4 m above sea level and the incline is generally in the region of 2.6 ‰. The tunnel measures about 8.4 m in width and stands around 6.2 m above rail level. There is no invert. Since the line was electrified in 1962 the tunnel has operated on a single-track basis with the rail track centrally positioned.

The tunnel is lined with stone masonry over its entire length. In some areas the abutments have been repaired with clinker brickwork. No inner lining was constructed in the abutment zone in those areas that were considered to be more stable. The interspace between the masonry and the rock was backfilled with quarrystone. This backfill is missing in many of the roof areas, thereby creating a series of cavities that are referred-to below as 'roof galleries' (**Fig. 1**).

The plan is to completely renovate the existing tunnel. As the highest point is at present within the tunnel and the minimum radius of 300 m is not met it will be necessary to adjust the axis and the gradient inside the tunnel and in the upstream sections of cutting.

The project zone forms part of the Rhenish Slate Mountains whose sediments were deposited in a marginal sea. In the northern and southern parts of the region were areas of dry land through which river systems transported the sediments into the Moselle-Lahn trough. This comprised a monotonous alternation of mudstones and siltstones along with quartzitic sandstones. The Lower Devonian rock is a joint aquifer in which the groundwater flows exclusively along the parting planes and in the faults. The rise in the terrain over a relatively short distance can result in comparatively large hydraulic gradients.

Close by are also to be found Quaternary sediments composed of Rhine sands and gravels (the so-called Middle Terraces), while talus deposits from the weathering products of the Lower Devonian layers are also present in some areas. These run horizontally above the tunnel in a series of furrowed Quaternary terraces (**Fig. 2**).

5 3D model

5.1 Creation of component Models

5.1.1 Soil Model

The tunnel runs through a Devonian interbedded sequence of mudstone and sandstone. The soil model was based on a point cloud of the terrain (Fig. 3) that was used to generate a digital model of the ground surface. A 3D solid was then developed from the model. A similar method was used for the modelling of the individual soil layers. The bedding boundaries and sequences were first broadly identified using geological data obtained from official geological records and the findings were then substantiated using the results of the core drilling programme. This resulted in digital terrain models of the horizon bases. 3D solid bodies were then constructed and subsequently merged with the ground surface. The result was a spatial representation of the foundation soil with all four existing strata layers. The soil model, which is visualised from a north-west direction, is shown in Fig. 4 and comprises interbedded layers of claystone and sandstone (red-green) and the Quaternary furrows (beige, blue and green).

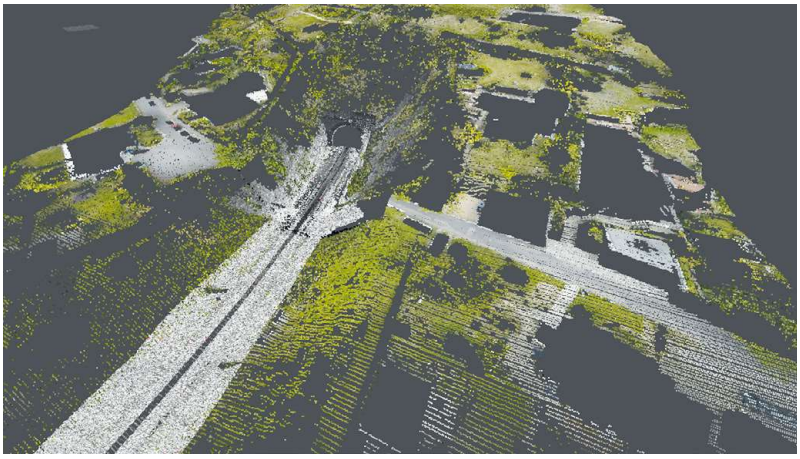


Fig. 3: Point cloud of terrain around the south portal [2]

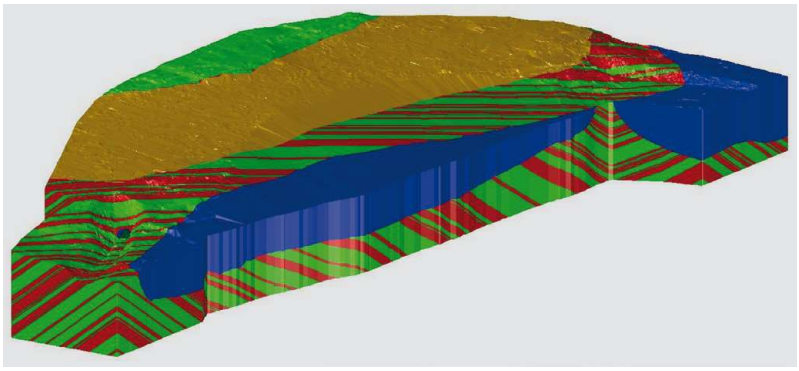


Fig. 4: Soil model [2]

5.1.2 Model of the existing Tunnel

The existing tunnel was generated using the available point cloud obtained from the laser scan of the tunnel face. The dimensions of the individual components, i. e. masonry/brickwork, backfill, cavities and track ballast, were modelled on the information obtained from the radial core drillings and various exploratory digs in the tunnel.

To this effect a series of transverse profiles were established at 15 m intervals along the tunnel axis to recreate the lining and inner structure of the tunnel. These profiles (Fig. 5) served to depict:

- The tunnel inner lining (red)
- The backfill (orange)
- The track ballast (light green)
- The roof galleries (blue-green).

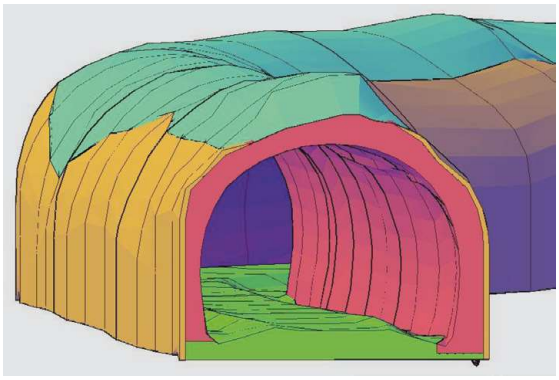


Fig. 5: Model of existing tunnel [2]



Using the transverse profiles, and again in accordance with the scheme as set out above, solid bodies were then generated to represent the original tunnel in three dimensions.

5.1.3 Model of the new Tunnel Design

For the purpose of the task at hand the model for the new tunnel design is only geometrically relevant in terms of the volume of excavated material. For this reason the modelling exercise only focused on the breakout contour and the inner and outer linings were not replicated. The first step in the modelling process involved the marking out of the planned new tunnel axis. The breakout contour of the new standard profile was then applied to this at regular intervals.

In this particular case a circular profile was chosen for the new tunnel structure. However, the design methods presented here can also readily be used to create other shapes, e. g. elliptical profiles.

5.2 Merging of the Component Models

After modelling the three component models these were merged together to create an overall model so that the resulting solid bodies could be used to determine the volume of material to be excavated. To this end the model of the existing tunnel was first cut from the soil model. The model was then re-inserted into the existing cavity so that the cropped cavity was filled with the master model. The roof gallery zone was at the same time modelled as a cavity. The model for the new tunnel design was then merged with the two existing unified models to produce a solid body that represented the entire volume of material to be excavated (**Fig. 6**).

5.3 Evaluation of the Overall Model

It was then possible to evaluate the amount of material to be excavated using the solid body that represented the intersection of all the models. The individual components of the breakout body can be selected in isolation so that the volume of each element (inner lining, backfill, ballast and rock) can be displayed separately. The volumes of excavation material determined in this way were then checked for plausibility. To this end the cubic volumes of the much simplified geometric models were first numerically and analytically calculated and compared. Following confirmation of the simple models the results of the detailed model were then compared with the available analytical mass calculations of the existing conceptual design [3]. The findings confirmed a very good degree of correlation.

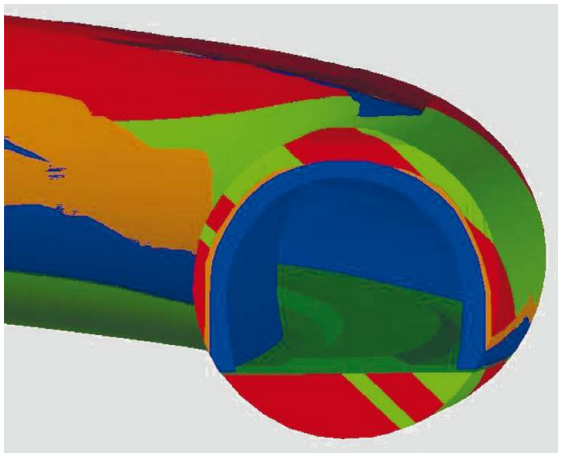


Fig. 6: Overall model of planned breakout volume generated by merging the component models [2]

6 Project Conclusions and future Prospects

The merged model, as derived from component models, has been presented in this paper as an example of how this methodology is developed and represents the current state of the art in science and technology. However it should be mentioned at this point that the software in question was in some ways 'misappropriated'. It is to be expected that even better and more refined software solutions will be available in the future. In practice, the accuracy of the models can also be improved by employing a higher exploration density. One aspect of particular note is that the complexity of the models and the large volumes of data involved call for increased computing power and performance. With even more complex models and far-reaching project settings likely to arise in the years ahead conventional end devices will no longer be capable of processing within a reasonable computing time the huge volumes of data generated by the modelling processes.

Digital planning will henceforth have an increasingly prominent role to play. The method presented here in relation to tunnel construction projects provides a very strong base for using and developing the opportunities that digitisation can offer when it comes to building within the existing structural fabric. New inner and outer tunnel shells, for example, can be modelled in three dimensions and then merged with the model of the existing structure. This means that the design specifications laid down in the relevant guidelines, such as the maximum values of the inner shell thickness in accordance with Deutsche Bahn regulation Ril 853.4004 [4], can also be incorporated into the model. When carrying out tunnel renovation projects various planning options (track radii, gradients and transverse profiles) can therefore be analysed and optimised in the early phases of the operation to take account of factors such as the breakout cubage, the filling of overbreak zones with shotcrete and the associated CO_2 footprint. By applying defined attributes in the BIM model the cubage data can also be used early in the project to predict and optimise other project-relevant parameters such as cost, time, sustainability and various waste disposal and health and safety issues.

For the sake of completeness it should be noted that the model example presented here was used for the further development of the BIM method as a good data basis was available. The actual project to restore the Horchheimer Tunnel is already well advanced and is not being planned according to the BIM method.

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7 References

Fromm, H.; Schmitt, J.; Schilder, L.; Nink, S. (2021): Der Einsatz von BIM-Modellen im Rahmen der Sanierung und Erneuerung von Eisenbahntunneln. GeoResources Zeitschrift (3-2021), S. 43–47. Online: https://www.georesources.net/download/GeoResources-Zeitschrift-3-2021.pdf.

[1] Fromm, H.; Krajewski, W.: Geotechnisches Gutachten, Erneuerung des Horchheimer Tunnel, Bericht-Nr. 03, CDM Smith Consult GmbH, Alsbach, 2014.

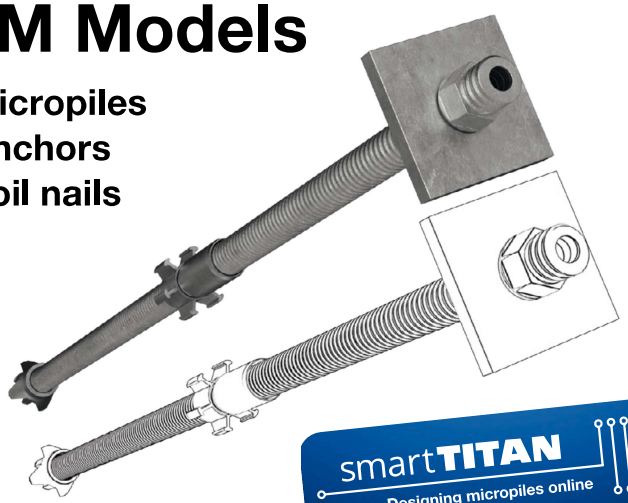
[2] Schilder, L.: Einwicklung eines 3D-Konstruktionsmodell für einen Bestandstunnel und anschließender Verschneidung mit der Neuplanung für die Erneuerung des Tunnelbauwerks zur Massenermittlung, Abschlussarbeit an der Hochschule für Angewandte Wissenschaften Darmstadt, 2020, unveröffentlicht.

[3] Biber, U.: Entwurfsheft Erneuerung Horchheimer Tunnel, Bung Ingenieure AG, Heidelberg, 2018.

[4] Deutsche Bahn AG: Ril 853.4004: Eisenbahntunnel planen, bauen und instand halten, Ausbau mit Ortbeton. Ausg. 2012-12.

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