Complex tasks to evaluate the feasibility of two railway tunnel variants in terms of tunnel construction

Joachim Michael
Prof. Quick und Kollegen – Ingenieure und Geologen GmbH, Darmstadt, Germany

Lisa Wilfing
Boley Geotechnik GmbH, Munich, Germany

ABSTRACT: The expansion/new construction of the railway line "Hanau-Würzburg/Fulda-Erfurt" is one of 13 infrastructural projects of the Deutsche Bahn AG that are to be implemented with high political priority. The new DB-Line Gelnhausen-Fulda is a sub-project of this infrastructure project with a section of approximately 42 km (variant IV) respectively 48 km (variant VII) and hence, the planned construction of up to 80 percent of each variant in a tunnel. From a geotechnical point of view, two route variants are examined in detail regarding feasibility of the tunnel construction and taking hydrogeological and natural aspects into account. Both variants have a very high impact and require very different requirements on the planning and selection of suitable tunneling methods. In this article the relevant geotechnical, geophysical and rock-mechanical investigations and findings are presented in detail as the basis of the decision-making process in finding the most economical and operational suitable route variant.

Keywords: Tunnel, Geotechnical Investigation, complex ground conditions, Building information modeling.

1 PROJECT OVERVIEW

The line between Hanau and Fulda is an important and intensively used railway line. Due to the congestion of the railway line, which is currently used by up to 300 local, long-distance and freight trains per day, the Gelnhausen - Fulda extension/new line project is intended to solve existing bottlenecks and to increase the existing capacity (see Figure 1). Furthermore, the new line is expected to significantly shorten the journey time for long-distance traffic.

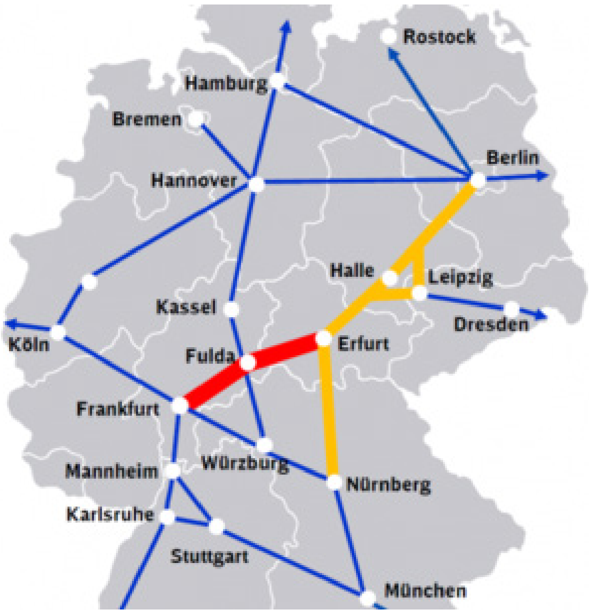

Figure 1. Planned extension/new railway line [source: DB AG].

The new line (red marked in figure 1) is subdivided into three sections: the upgraded line Hanau - Gelnhausen and the new lines Gelnhausen - Fulda and Fulda - Gerstungen. Concerning the new line Gelnhausen - Fulda, two potential routes between 44 km and 48 km long (variants IV and VII) were selected from a large number of variants for the section of the NBS, on which a subsoil investigation is being carried out in parallel to the ongoing regional planning. The subsoil investigation campaign is structured in several stages. On the basis of the findings from the as-built documentation and the investigations of planning stages 1 and 2, a reliable and profound decision is to be made on which of the variants should be object to further investigation, planning and construction.

2 SPECIAL CHALLENGES DURING FIELD INVESTIGATIONS

For geotechnical, geological, hydrogeological and, in the Central Hessian Mountains partly also for morphological reasons, the project area places special demands on the subsoil investigation measures. These are predominantly rocks of the Germanic Triassic (Buntsandstein and Muschelkalk), i.e. units of the overburden whose by origin horizontally bedded layers have been fractured, tilted and dislocated by repeated tectonic processes. In the Tertiary period this area was strongly affected by volcanism. The morphology is characterized by basalts, tuffs and weathered horizons of varying thickness. Karstification-prone rocks within the Zechstein, Rotliegend and Triassic formation are limestones and dolomites, gypsum and salt; karstification phenomena in form of sinkholes and subrosion depressions were generally known from previous literature and from tunnel drives already carried out for the line Hannover-Würzburg and were therefore explored and evaluated with special focus to the planned new tunnel drives. Due to the proximity to a salt deposit, possible mining impacts had to be considered. Parts of the two variants tend to have pronounced landslides close to the surface.

From a hydrogeological point of view, there were special requirements for the exploration since there was a risk of drilling artesian aquifers and requirements for the protection of mineral springs had to be considered. Furthermore, consistent data had to be obtained for the (pre-)dimensioning of the engineering structures in this tectonically highly fractured area. Because numerous water extraction plants are operated in aquifers at different depths, extensive additional precautions (technical and licensing) were already to be planned and carried out with regard to the evaluation of possible effects of tunnelling work (e.g. fine freight input, etc.) by installing ultrafiltration plants into the water extraction plants in order to detect possible fine freight input when sinking the exploratory boreholes while at the same time ensuring the unrestricted function of the water supply.

In addition to typical ground exploration boreholes down to a depth of approx. 190 m and their development to groundwater monitoring wells, further extensive geotechnical borehole tests have been applied such as borehole dynamic probing , hydraulic fracturing , hydraulic testing of pre-existing fractures, borehole expansion tests using lateral pressure and dilatometer deformability testing instruments as well as hydraulic borehole tests (water pressure tests, infiltration tests) and geophysical borehole tests (optical and acoustic borehole scans, conductivity and temperature measurements, spectral Gamma Ray Log). In the northern sections of the route, which are close to known sinkholes or subsidence areas, a combined surface geophysical refraction and reflection seismic survey was also carried out over a length of 22 km.

3 DIGITALIZATION AND BIM IN GEOTECHNICS

For some years now, building information modeling (BIM) must be applied for new large scale construction projects (BMDV, BMWSB). The aim of the BIM method is the creation of three-dimensional building models, which contain predefined components and structural elements. Such predefined models do not exist in geotechnical modeling. In principle, a building structure model can be used at any location on earth, whereas a ground model is site-specific and, due to its natural formation, is not generally reproducible and geometrically heterogeneous in nature.

In terms of cooperation in digital planning diverse specialist models are required and put into the coordination model of the project. So far, the requirements for the BIM model have been based on the fields of structural engineering and infrastructure planning. A specialist model “ground” significantly differs from other specialist models (e.g. structural engineering, signal technology, buildings, etc.) in terms of its content structure.

3.1 Specialist model “ground”

The specialist model “ground” is an attributed and parameterized 3D ground model supplemented by various sub-models (Molzahn et al.). The integration of the specialist model “ground” into the overall BIM model is required to take the properties of the ground into account during the planning phase and to evaluate the information for processes and cost forecasts. In the meantime, there have been basic proposals made in literature reaching from a lot of recommendations from various working groups such as the DAUB, etc. to national and European standardization groups regarding the contents and structures of the ground model. In the position paper of the Federation of the German Construction Industry, Federal Department for BIM in Foundation Engineering, it is pointed out that the implementation of use cases represent a complex process flow that relies on different tools of digitalization and requires the participation of all project participants. The implementation of these suggestions, recommendations and proposals must, however, be equally consistent with the use cases (AwF) that the client specifies with their employer’s information requirements (EIR resp. AIA) for BIM planning. AIA will not be discussed further as these tools of digitalization are subject to an intensive process of standardization and to a rapid progress in software development.

3.2 Sub-models of specialist model “ground”

The specialist model “ground” itself will cover various sub-models such as digital elevation model, drillings, ground layers, homogeneous areas, geotechnical data, groundwater, etc. and hence, contains all information deriving from archive to actual findings (Molzahn et al.). However, the specialist model “ground” is only valid in connection with the geotechnical report.

3.3 Project example DB NBS Gelnhausen – Fulda

For the planning of the new line Gelnhausen-Fulda, the application of BIM was specified in accordance with the contractual specifications and with reference to the AIA, and a specialist model “ground” had to be created.

The modeling procedure started with the import of the digital terrain model, which was provided by the AG initially as DGM10, later as DGM1, for a 400 m wide corridor from aerial data. Here, the routes of the two variants as well as the existing and planned drilling locations were incorporated. In addition, geological profile sections from the geological map were implemented in pdf format informatively, not providing digital content. In parallel, a sub-model of the specialist model for the drillings named “geology” was prepared with the existing geotechnical indications from archive drillings. As the exploration progressed, the new drill core profiles were converted into digital information with attributes and parameters derived from laboratory and field tests and transferred to the specialist model “ground”.

The uncertainties that arose after measuring the boreholes to DGM10, initially resulted in errors in the extrapolation of layers, which were corrected by manually reworking the terrain surface at the borehole approach point. Later, it became apparent that this resulted in significant sources of error in the IFC-export files, which could only be corrected if DGM1 was imported.

For modelling the ground structure, i.e., connecting the information from the borehole profile with surrounding borehole profiles, the applied software offers various technologies; quite satisfactory solutions could be found via the mathematically (geostatistical) defined kriging.

Whereas the modeling of the ground with the applied software Leapfrog Works® took some extraordinary efforts due to the large and complex project area and tectonically highly fractured rocks but ending successful (see Figure 2), it was not possible to create a sub-model “groundwater” with respect to the large distances between the exploration points (due to planning phase 1 - 2), the very complex geological and tectonic situation and hence, a lack of consistent and reliable information along the line. This is not a BIM problem, but an interpretation problem. Information on detected groundwater in the boreholes is therefore provided with the sub-model “geology” only. Furthermore, the implementation of geophysical survey data was not successful up to now.

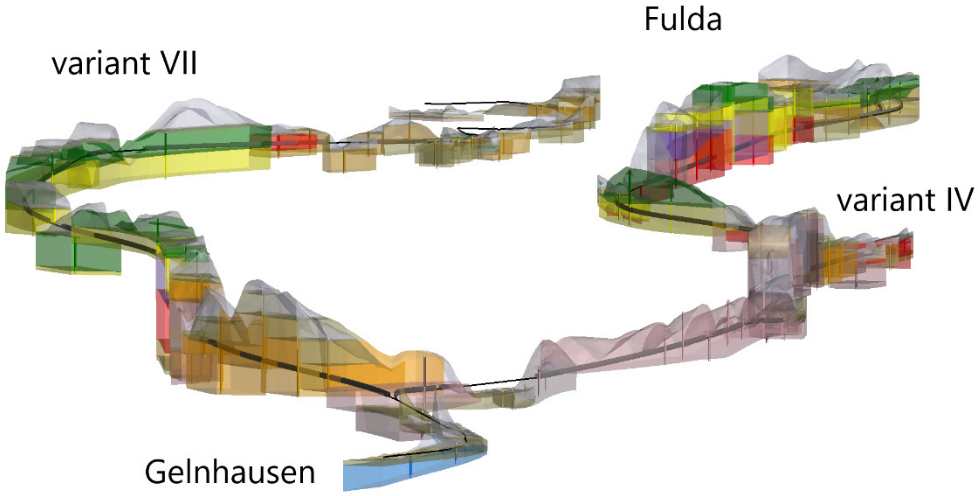

Figure 2. Specialist model “Ground” for the new line Gelnhausen-Fulda.

Concerning the handling of transforming digital data into IFC-files according to the AIA, the problem arises that general information of the drillings such as height, coordinates, date of drilling, detected groundwater depths, filter section of monitoring well etc., could not be provided together with the stratigraphic information. Consequently, an additional sub-model “general drilling data” has been generated.

4 CHALLENGES FOR TUNNEL CONSTRUCTION

According to the regulations, the new line consists of two parallel single-track tunnels that run at a distance, which is yet to be planned. The route on which the explorations are based thus marks an imaginary axis between the two tunnel axes.

Within the scope of the tunnel construction evaluation, the currently conducted exploration stage 2 showed the possible tunnel construction technologies and their areas of application. This resulted in particularly challenging areas, which need to be further investigated regarding the basic feasibility of the tunnel construction. Among other things, the passage of drinking water and mineral water protected areas and applicable tunnelling technologies must be clarified in terms of the licensing law, possibly in connection with replacement water procurement measures, carried out in advance.

For the tunnel drivings in the Mesozoic solid rocks, for which experience is already available in the project area for both shotcrete and mechanized tunneling technologies, mixed-face conditions such as different rock strengths, fault zones and possibly karst phenomena must be taken into account. The excavation scenarios listed below, however, pose special challenges regarding the driving technology:

- driving in swelling Tertiary silts and sands (tmi);
- driving in swelling Tertiary silts and sands (tmi) with approaching and striking basalt from above into the excavation section of the tunnel and/or encountering vertical basalt veins;
- driving at the boundary zone of Mesozoic bedrock and Tertiary silts and sands;
- abrupt, fault-related vertical changes between soft and hard rocks.

Figure 3 shows an exemplarily part of the driving scenarios mentioned before, for a tunnel section of variant IV with a length of approx. 10 km. Possible driving technologies will also be evaluated for variant VII after the exploration measures have been completed. By now, it can already be stated that the special challenges described above are of the same nature but extend over significantly longer driving sections.

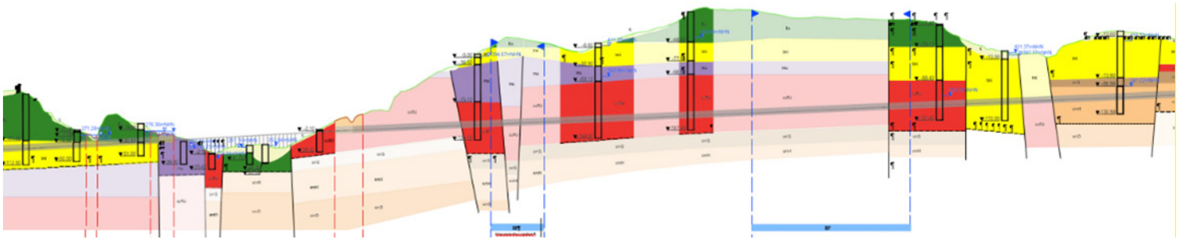

Figure 3. Longitudinal section (ca. 10 km length) showing driving sections posing special challenges.

Once the decision has been made as to which of the two variants is to be investigated and planned in more detail on the basis of all the factors of concern (nature, environment, technology), it will be necessary to show further detailed planning for the conventional and mechanized construction methods under which boundary conditions and with which tunnelling technology and additionally required measures, the tunnels can be excavated in a stable manner, without impacting on protected assets and neighboring structures. This must also be investigated for the construction of the connecting structures.

5 CONCLUSION AND OUTLOOK

With the geotechnical, hydrogeological, and tunnelling exploration strategies presented, the foundations for planning and execution were created in accordance with the generally accepted codes of practice and the state of the art, particularly for the tunnel drivings. As an additional contractual task, these basics were also digitally prepared using the BIM method. The development of the BIM application in the planning phase to a mature standardized application in infrastructure projects, is the focus of DB AG's BIM strategy in BIM Phase 2 - Digital Competence until 2025, to complete the digital transformation of BIM Design and Construction from 2025 in BIM Phase 3 and to transfer it to the regular state. Research projects (e.g. German Centre for Rail Transport Research) are currently underway to investigate the possibilities of combining BIM and GIS with a transition from local, object-related coordinates from BIM planning to global, geodetic reference systems, which should enable georeferencing and the inclusion of available geodata in the BIM system (DZFZ).

The state of research and science in BIM is much further advanced than practice as normative regulations (ISO, CEN, DIN, VDI) are currently being developed and soft- and hardware requirements are highly complex and expensive. Employees need be trained and educated in a cost-intensive manner, and there is currently no foreseeable fee-based remuneration for these additional and very vaguely describable BIM services. In current tenders, BIM suitability criteria are already required as part of the prequalification process and demanded in the contractual specifications with reference to the AIA but are only occasionally requested with a corresponding remuneration item in the tender. Fees for services for BIM geotechnics are currently not regulated e.g., in the HOAI, but might be declared as special services.

The spatial modeling simulates an accuracy at every single point of the specialist model "ground" that does not exist. This raises the question of the responsibility or liability aspects for geotechnical experts for this kind of information outside of the ground investigation. These questions are of great relevance in the context of planning, but especially with the execution of construction (claim management).

With regard to the required approval of plannings by Approval Experts of the Federal Railway Authority (EBA-PSV), many aspects still need to be clarified; in this case, the Federal Railway Authority has launched a research project via DZFZ to identify and evaluate BIM inspection routines for authorities.

ACKNOWLEDGEMENTS

We would like to thank Deutsche Bahn AG, Gelnhausen-Fulda project for permission to publish.

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