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Construction of the New High-Speed Railway Line Ulm–Wendlingen in Karstifed Rock

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Abstract

The new railway line from Wendlingen to Ulm (in Southern Germany) is currently under construction. With planned travel speeds of up to 250 km/h the slab track system will be used as track superstructure. The high-speed line is crossing the Swabian Alb, whereby on a distance of about 23 km karstified jurassic terrain is being crossed. After an overview of the project this publication provides information about general problems induced by the construction of a slab track type high-speed railway line on karstified sub-soil. Typical examples of the geophysical karst investigation program and the karst phenomena found in this project are given. Furthermore the static/cyclic FEM-calculations for the proof of relevant cavities are being displayed. The publication is completed by a presentation of particular measures which were used for the strengthening of the subsoil.

Keywords: High Speed Railway; Slab Track; Karst Investigation

1 Introduction

The railway project Stuttgart–Ulm comprises the two partial projects "Stuttgart 21" and the new railway line from Wendlingen to Ulm. "Stuttgart 21" consists of the complete realignment of the Stuttgart railway traffic junction with a new deep-tunnel station as centerpiece and the connection to the airport as well as the further alignment towards Wendlingen. Being part of the „Prior-ranking Axis No. 17" of the trans-European Railway (Paris–Budapest/Bratislava, so called „Magistrale für Europa"), Baden-Württemberg will be permanently connected to the European high-speed railway line network, Fig. 1. With planned travel speeds of up to 250 km/h the slab track system will be used as track superstructure.

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Fig. 1.Trans-European line Paris–Budapest/Bratislava, Stuttgart

The project section stretches on the plateau of the Swabian Alb between Hohenstadt in the west and Dornstadt in the east. Most of the line parallels the federal highway A8 in the open air, the latter being widened from four to six lanes at the same time. The highway and the railway line run in a distance of mainly 29.95 m to each other (Fig. 2). The roll-off rampart serves as a barrier for the railway line against deviated vehicles from the highway and as a visual separation in order to avoid irritations of car drivers by oncoming trains on the parallel railway line. The new railway line is led through water protection areas.

For construction purposes the plateau of the Swabian Alb is divided into three sections of approximate length which are being started subsequently from east towards the west, together with the extension of the motorway. The fourth awarded section is being formed by the tunnel Widderstall with a length of just under 1000 m. This tunnel is the largest single structure of the project. Furthermore three minor tunnels are installed. Traffic routes crossing the motorway and the new railway line are being led either under or over the alignment. The matching bridge structures are combined with retaining walls which are leading the maintenance road running alongside the alignment either up or down to the crossing traffic route. On the whole 19 bridge structures are located on the Swabian Alb plateau, plus two bat passages as extraordinary structures.

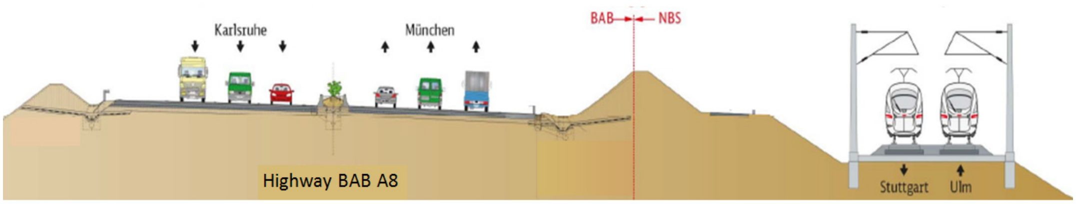

Fig. 2. Cross Section

The section of the Swabian Alb plateau is characterized by heavy earthworks and rock construction in order to install the cuts and embankments as well as the excavation pits for the structures. A particular challenge results from the karstified subsoil/rock, which was already subject of special attention during the draft design phase, in order to be able to define the contractual baselines for the investigation during construction as well as remedial actions. In the following the proceeding during the subsequent project phases is shown by which the high requirements regarding the subsoil resulting from high speed traffic on the slab track system shall be fulfilled.

2 General Problems resulting from Karstified Rock

On the plateau of the Swabian Alb karstified bedrock is crossed on a length of about 21.5 km. The stratification and subsoil conditions are mostly characterized by the limestone of the Weissjura Jurassic Mountains (on a length of about 18.9 km) and in some areas by molasse sediments (on a length of about 2.6 km in the east).

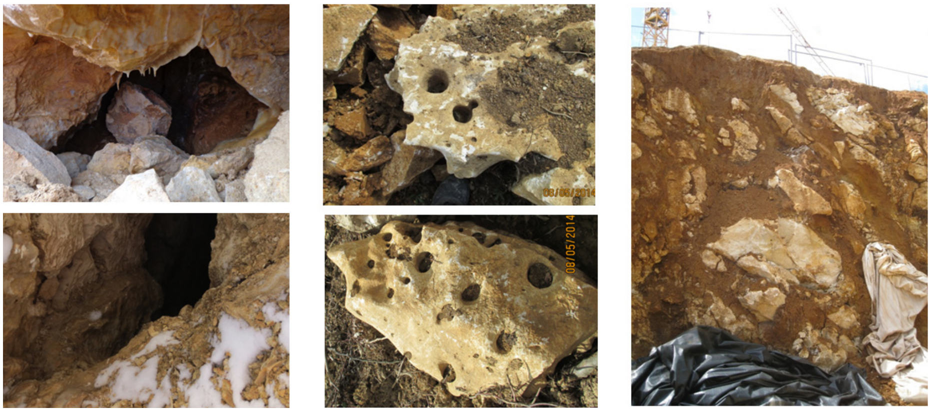

Fig. 3. Karstified Rock

The karst process has primarily taken place during the Kretacious Period and during the Tertiary. Large valley systems were formed and a karst relief with partly deep karst cavities on the terrain surface (such as pools, sinkholes resp. dolines, funnels and cracks). Furthermore complex cave systems were formed in dependence of the existing drainage systems. Whereas in limestone mainly the crevices are affected by karstification which are thus widened/extended, the karstification in dolomite rock and dolomitized limestone occurs more extensively and intensely due to its higher solubility and thus proneness to karstification. The karstification does not occur uniformely but with locally differing intensity. In consequence a very heterogeneous but nonetheless intact bedrock was formed, in which karst formations differing in type and dimension are spread randomly within the unkarstified rock, Fig. 4. In sedimentation periods in some areas existing karst cavities were sealed.

3 Investigation and Detection Concept

3.1 Draft Design

As basis for the control of the karst phenomena during draft design a Real-Case-Prognosis method was developed which renders possible an evaluation of the pre- and main exploration and by which the experiences made during the preceding construction of the railway line Nuremberg-Ingolstadt are taken into account.

The Real-Case-Study contains an overall evaluation and assessment of the data and results derived from investigation programs, aerial photos, mapping and research. As a main feature a specific classification of borings is carried out which for this purpose are divided in segments of 5 m length. Each of the 5 m-segments (out of approx. 450 borings) is assigned to a category ("light", "moderately" or "intensely karstified").

In a next step the detected cavities underwent a statistic analysis depending on their size. From the frequency of occurrence in the borings the frequency of occurrence on the entire project can be derived. As an outcome quantity calculations are carried out which render possible a constitution of the contracts with regard to the effort for investigations and remedial works of relevant karst phenomena. Thus a quantitive prognosis is determined even though the exact localization is not yet possible. This local concretion is taking place in the investigation during construction which is carried out after reaching the foundation level and is described in the following.

3.2 Investigations during Construction

The main purpose of the investigation program during construction is the detection of weak zones in the rock due to karst by indirect methods, whereas the focus lies on the detection of cavities (air-filled as well as partly or completely filled by sediments/debris). By geophysical investigation methods physical parameters (e.g. potential fields and wave velocity) are recorded, the extension of which is influenced by the properties and composition of the subsoil. In contrast to direct investigations such as borings, soundings and trial pits, which are merely providing information about the exact location/investigation point, geophysical measuring methods provide large-scale and continuous area-wide results.

The superficial geophysical investigation of the entire area of the railway line (means all cuts and embankments) includes gravimetric and seismic measurements. The gravimetry is executed in a grid of 2 x 2 m over the complete foundation area. Alongside the center of the track 2 seismic profiles are being generated. The surface geophysics have to ensure that in a max. depth of 2 m cavities with a diameter of ≥ 1.5 m are detectable, as well as cavities with diameter ≥ 2.5 m down to depths of 2 to 6 m and cavities with diameter ≥ 5 m down to depths of 6 to 10 m, see Fig.4.

The results of the superficial geophysical exploration are being displayed by mapping of an aberration index (Fig. 5). Aberration indicators 0 and 1 reveal that definitely no relevant cavities are existing; in these areas no further investigation has to be done. Index values of 2 to 5 are yielding areas of suspected increasing intensity of karstification. With regard to economic aspects it is of prime importance that the foundation areas of an index factor 0 and 1 are not being investigated further. Areas with higher index values undergo a systematic follow-up investigation by borings arranged in a grid which may be further densified depending on the results.

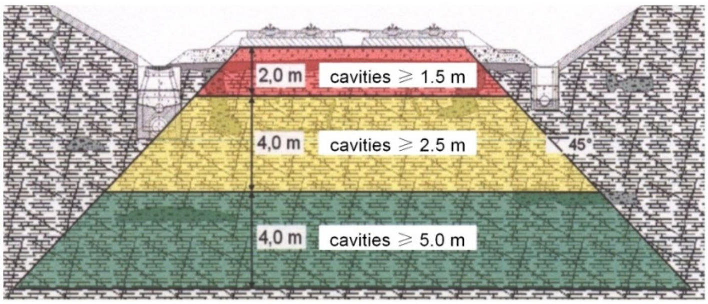

Fig. 4. Requirements for Surface Geophysics

The investigation of all bridge foundations (foundation levels with limited area) is generally carried out using borehole geophysics (crosshole/downhole measurements). Using borehole geophysics cavities of a diameter of 1.0 m (max. 1.5 m) will be detected, regardless of depth. Results derived from the borehole geophysics are being edited as tomograms. The displayed seismic wave velocities can be transmitted quasi directly into anomaly indicator areas due to the high resolution.

By the follow-up investigation also the required calibration of the geophysical methods is provided which has to accommodate the rock formation. Changes in the rock formation require a new calibration. From the entirety of all direct and indirect explorations and monitoring results the rock model is derived which is decisive with regard to geotechnical and foundation matters.

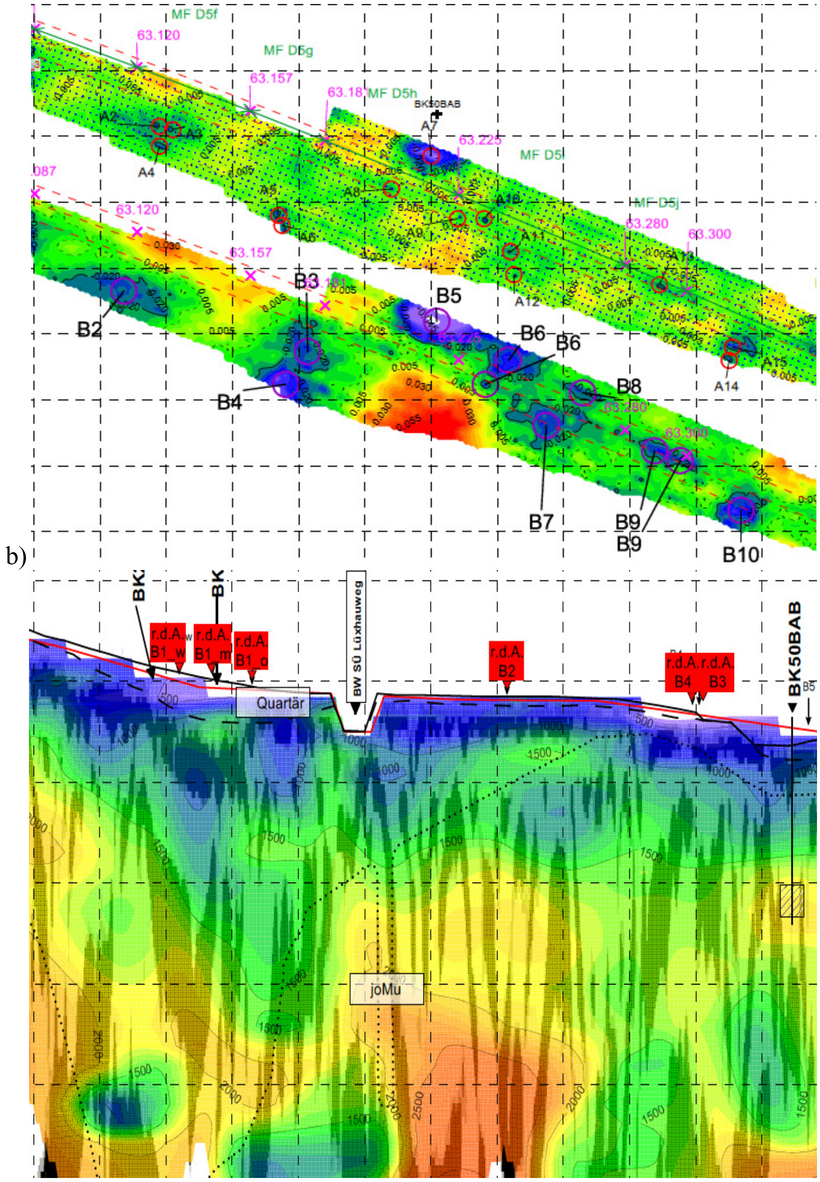

Fig. 5. Example Surface Geophysics a) Gravimetry b) seismic (Fugro)

3.3 Calculations under Consideration of Relevant Cavities

Relevant diameters of karstifed cavities are securely being detected and treated by engineering measures (Fig. 4) and subsequent remedial works. After execution of the respective exploration and construction works the existence of untreated cavities with bigger dimensions has to be excluded with sufficient certainty in the foundation area of the new railway line.

With remaining cavities of the above-mentioned relevant size, the stability has to be checked by means of structural analysis in order to guarantee the long term serviceability of the track. Respective proofs were developed when building the preceding high-speed railway line Nuremberg–Ingolstadt. These analyses were supplemented by further analytical calculations with the rock parameters of the Swabian Alb (Fig. 6). Under consideration of the input values the results of these calculations can be used to assess and evaluate the quality and stability of the subsoil under comprehension of the grade of mechanical defects/crevasses of the rock on-site. The statical analyses were supplemented by dynamic numerical calculations with the finite element method using two- and three-dimensional models, varying material parameters for the solid rock (Fig. 7) and different locations of the cavaties related to the track axis. The cavity to be generated was reproduced in the statically most unfavorable form of a cube.

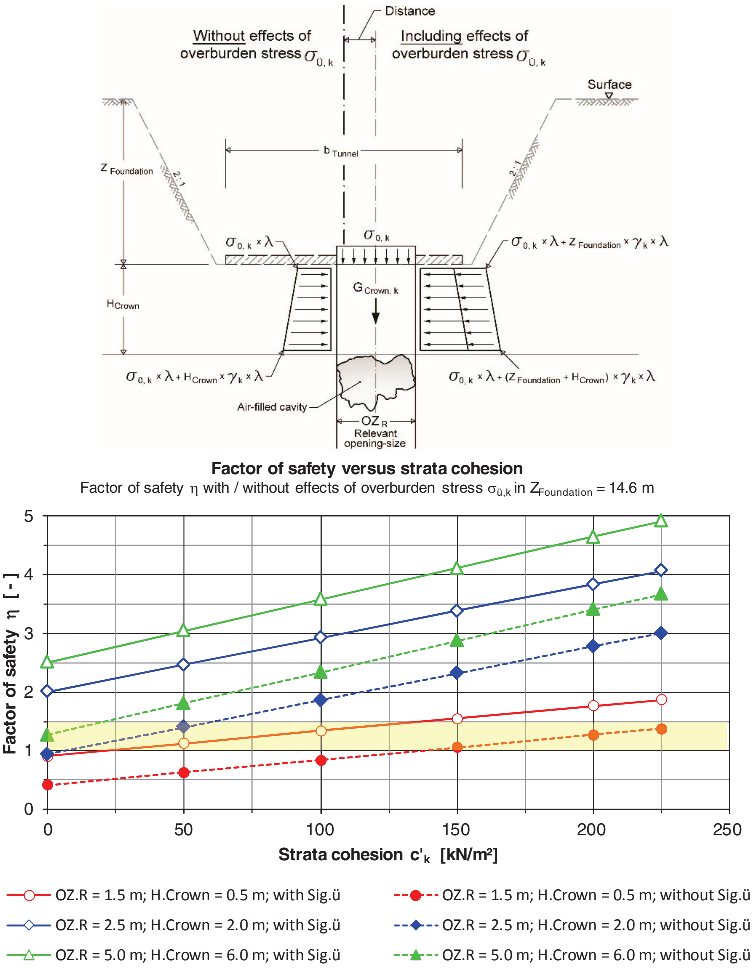

Fig. 6. Analytical Calculation Model and Typical Results

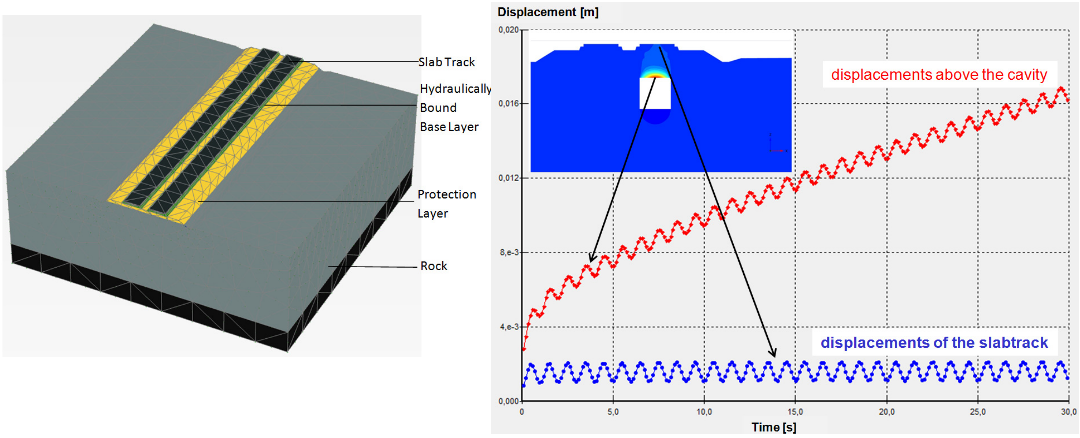

Fig. 7. Numerical Calculation Model and Typical Results

Fig. 7 shows that regardless a calculated failure of the rock structure in the ridge of the generated cavity no seriously damaging increase of deformations in the area of the above track is calculated.

3.4 Dynamic Preloading

Prior to the foundation works an area-wide dynamic preloading is performed. One aim of this proceeding is to anticipate the dynamic impact of the subsequent railway traffic by a multiple of its amplitude and thus cause the collapse of near-surface cavities. On the other hand variations in the resolution and thus possible deficiencies of the near-surface geophysics are being compensated down to a depth of approx. 2 m below the investigation level. The dynamic preloading is applied by a heavy, dynamic, mobile test roller train or single roller with polygonal lining. The actual dynamic impact due to the preload is documented by monitoring the oscillation velocities (calibration). The documented effective oscillation velocities at 0.5 m depth ($v_{eff} \geq 50$ mm/s) are ten times as large as those caused by railway traffic (determined by calculations and measurements to about $v_{eff} = 5$ mm/s).

4 Structural Measures

Detected karst cavities which might be hazardous for the stability and serviceability of the railway track are subject to remedial works prior to the beginning of further construction measures. Generally the cavity is being filled with filter stable aggregate material and concrete. Ahead of the fill usually a layer of coarse-grained sand-gravel-material is applied and before the placing of the concrete the location and disposition of the gravel-sand-material is checked by camera inspection. In case of doubt the thickness of the sand-gravel-layer is increased. Thus the concrete is prevented from leaking into deeper rock levels which may be relevant for e.g. water protection and management, respectively. In cases where the detected weak zones are situated in rock with e.g. locally concentrated narrow and open fissures the treatment is executed by grouting. The sand-gravel-mixture taken for concrete is then replaced by an especially stiff grout which can be injected slowly under low pressure in order to create a clogging e.g. at a bottleneck within the fissure. As soon as the possibility of an unintentional leakage of the grout is eliminated the filling process itself is being started.

5 Summary and Experiences

For the structurally engineered control of the karst subject a real-case prognosis of weak zones caused by karst was carried out during draft design, focussing on air-filled cavities. In order to ensure permanent stability and serviceability of the track and to eliminate the possibility of relevant cavities with sufficient reliability, the foundation level is being investigated during construction using geophysical methods. Detected karst phenomena are being analyzed in detail using direct investigation methods. Furthermore an area-wide dynamic preloading is carried out. The restoration of weak zones in the bedrock caused by karst is being carried out using mineral mixtures and concret.

At the present state (as a snap-shot of the situation), the karstified subground detected on site can be characterized as follows: The number of cavities is exceeding the prognoses. In the vast majority this is a matter of smaller cavities, which may remain open or can be very easily treated according the criterion of relevant cavities. Medium size cavities were detected significantly less often than anticipated. Up to now, one bigger cavity was found (cave of approx. 500 m³ in a slope at the Widderstall tunnel, Fig. 8). So far, the effort and costs for the restoration of cavities on the Swabian Alb are lying well below the anticipated amount.

The execution of the karst investigation shall be completed according the planned schedule within the course of the year 2016 for those parts of the alignment which were expected to contain the most intensively karstified areas.

Fig. 8. Cave in a slope of the building pit at the Widderstall tunnel

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