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TUNNELLING FOR GERMAN HIGH SPEED RAILWAY LINES

• A GENERAL REPORT

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ABSTRACT

Several high speed and extension railway lines are under construction or in planning progress in Germany (table 1). In the course of the planning of these new railway lines a great proximity to existing transport routes was desired for reasons of environmental protection. As a consequence highways must be undercrossed several time with partly very little covering heights. The undercrossing of built-up areas was accomplished by massive additional measures from within and outside the tunnel in order to stabilize the ground - especially the tunnel face - to minimize deformations and to guarantee the stability and the serviceability of the tunnel itself as well as of building structures above the tunnel. The in general double-tracked tunnels are constructed mostly in an universal driving with sequential excavation of crown/bench/invert in shotcrete tunnelling method. Alternative driving techniques such as universal drivings with a preliminary pilot tunnel or side wall drifts under application of a groundwater relaxation hurrying on ahead, drivings with air-compressed stabilization of the face and shield drivings are presented and discussed on the basis of performed drivings and feasibility studies. A special tunnelling technique that has been applied in Berlin will be described. A short survey on some results of the geotechnical and geodetic monitoring and the effect of optimised tunnelling techniques will be given. Prior construction large investigation programmes have been carried out; efforts to determine the ground risk and to evaluate the remaining risks will be pointed out.

1 INTRODUCTION

Since the 80s, the Deutsche Bahn AG is building high speed railway lines throughout Germany.

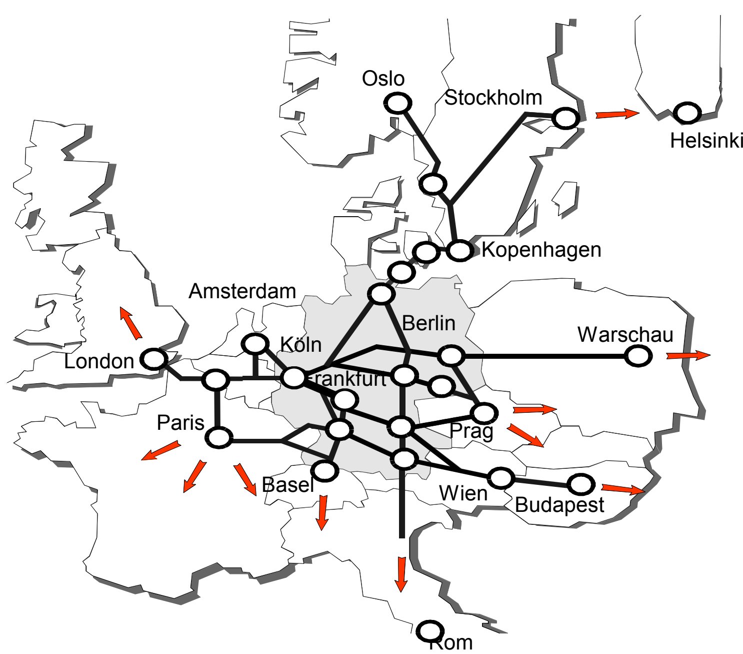

Fig. 1: European railway network

The new lines are part of the national and international railway network in Europe (fig. 1). A main attribute for safety, serviceability and for the comfort criteria of the route are the geotechnical properties which are found under the alignment of the route.

2 TECHNICAL REGULATIONS AND GROUND RISK

The ground model (description of layers, schists, lateral and vertical extension, soil and rock mechanical parameters, ground and rock behavior) is determined by historical research in a first step followed by a high-quality ground investigation. Available experiences from the ground have to be put into the evaluation of the results of the investigation. An insufficient ground investigation can result in delays and additional costs, though this can also occur, when working within these regulations.

Technical regulations define the requirements of type, extent and quality of the geotechnical survey measures. During and after the ground investigation the geotechnical expert or tunnelling consultant has to control, whether his program fulfils the demanded aims under respect of the planning phases sufficiently; if this is not the case, he must indicate and state this to his client immediately. Now - if necessary - further investigation measures can be specified.

Main risks, which result from the natural and from anthropogenic affected ground conditions have to be pointed out. At this time a first estimation of possible ground risks and their contractual consequence can be specified. In the geotechnical expertise this might be carried out according to the following manner:

A facts on geology and hydrogeology
B facts on environmental geotechnics
C recommendations for the design and construction
D assessment of ground risk

In Germany the ground risk is from legal view indisputable up to the client; the question, when it occurs will be differently evaluated from the client's and from the general contractor's point of view, however.

The technical risk is generally defined as the product of extent of the damage and the probability of a damage entrance. The ground risk is defined as follows in the draft of the German technical rule DIN 4020 version:

"*Ground risk is an unavoidable residual risk lying in the nature of the thing, that with utilization of the ground itself or the use of the contents within the ground (groundwater, contamination, etc..) can lead to unforeseeable effects or complications, although that, which provides the ground, fulfilled its obligation for complete investigation and description of the building ground and groundwater conditions according to the technical sets of rules, and although the contractor followed his own responsibility to proof and to indicate.*"

The natural and the anthropogenic ground risks as well as technical risks have to be determined and consequences regarding construction an costs have to be carried out by a risk management.

However, not only the tunnelling expert on the client's side has to refer in the context of its responsibility about possible remaining ground risks, but strongly the contractor too.

3 TUNNEL CONSTRUCTION IN BERLIN

After Germany's reunification and the German Bundestag's decision of June 20th, 1991, to make Berlin the new German capital, Berlin's once exemplary subway and railway network is being restored and adapted to the new demands in order to make Berlin a powerful transport center in Germany and Europe.

3.1 Long-Distance Railway Tunnel

The long-distance and regional railway tunnel with a length of about 9 kilometers connects the northern and southern part of Berlin. At the core of the new train connection the about 2,5 km long tunnel is situated between the House of Parliament in the north and the Gleisdreieck in the south (fig. 2).

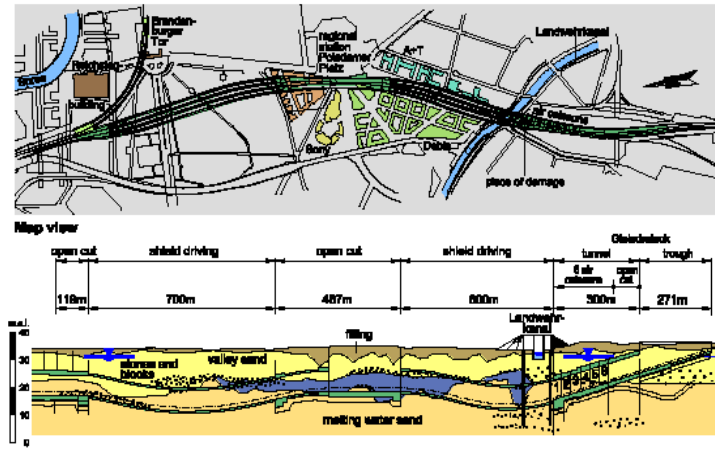

Fig. 2. Project site in plan view, geotechnical longitudinal section.

The four circular tunnel pipes have external diameters of about 9 m and with their floors are situated 20-25 m deep under ground surface. While the underground buildings in the area of the regional station „Potsdamer Platz" and „Platz der Republik" are built in open cut technique and the ramps of the Landwehrkanal in air caisson technique the closed mining technique is applied on the about 700 m long section between House of Parliament and Lénné-Dreieck and on the about 500 m long section between Potsdamer Platz and Landwehrkanal.

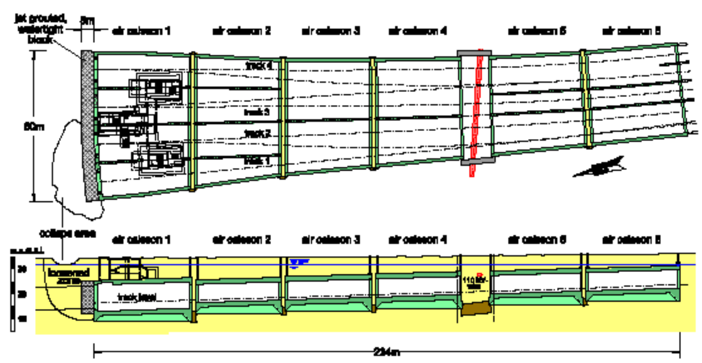

Fig. 3. Air caissons 1-6, plan view and longitudinal section

The tunnel building Gleisdreieck with its up to 23 m deep building pit is constructed in caisson technique with 6 air caissons (fig. 3). The air caisson 1 in north-western direction has a width of about 60 m, and parallel to the route approximately 40 m. Its height from the caisson cutting edge up to the ground surface is 25.5 m, in which the access buildings are included. At the transition from open-cut to mining technique, i. e. directly in front of the northern external wall of air caisson 1 a sealing block was jet-grouted which after the opening of the gland has to ensure stability and water impermeability until the shield driving machine takes over this function.

4 NEW HIGH-SPEED AND EXTENSION RAILWAY LINES

In the following selected new railway lines of the Deutsche Bahn AG, the geotechnical boundary conditions and tunnelling methods and results of the drivings are described.

Railway Line	Cologne / Frank-furt	Frank-furt / Mann-heim	Karls-ruhe / Basel	Stutt-gart / Ulm	Erfurt / Leipzig	Ebens-feld / Erfurt	Nuremberg / Munich
entire length of the route [km]	ca. 204	ca. 82	ca. 270	ca. 55	ca. 127	ca. 105	ca. 170
amount of bridges	18	1	0	1	6	29	7
amount of tun-nels	26	3	3	5	3	22	9
entire length of tunnels [km]	47	5	15	24	15	41	26
longest tunnel (m)	Schul-wald 4.495	Lorsch 1.375	Katzen-berg 9.385	Alb-aufstieg 8.710	Finne-tunnel 6.886	Bleß-berg 2.314	Euerwang 7.700
max. speed (km/h)	300	300	250 (200)	250	250 (300)	250	300

Table 1. New high-speed and extension railway lines in Germany recently constructed, under construction or in planning progress

4.1 NEW HIGH-SPEED LINE COLOGNE - FRANKFURT

The new line connects both city centres on the shortest way through the Rhenish Massif. 18 bridges and 26 tunnels of altogether 47 km length had to be constructed, 6 tunnels were erected in open cut technique (table 1).

Geology and geotechnical conditions: Heavily tectonically stressed Devonian claystones, Tertiary vulcanites, Tertiary and Quaternary loose ground, profound decomposition.

Characteristics: Drinking water and water protection zones, aggressive groundwater, old mining areas, landslides, earthquake area.

4.1.1 Tunnel Frankfurt Intersection

Directly adjacent to the new railway station at the Frankfurt airport the construction of the double-tracked tunnel was started in December 1995. The undercrossing and the parallel development of the Frankfurt highway intersection despite the large traffic flow was one of the challenges in the construction of the new railway line Cologne-Frankfurt.

Ground / Groundwater. The ground is characterized by fills and an interchange of Quaternary river sediments with layers of silt and clay. The covering height is up to 15 m. The groundwater surface is 16 m under ground surface, slightly below the crown feet.

Geotechnical and Engineering Conditions. The geotechnical and engineering conditions for the undercrossing of one of the most frequented highway intersections in Germany relevant to the chosen construction method were:

- tunnelling under fills in loose ground with low cover
- no further groundwater lowering allowed
- no disruption of the traffic flow at the Frankfurt highway intersection
- limitation of the deformation at the ground surface (highway) to a maximum of 5 cm.

The proof of the stability of the face and the proof of the safety against failure of the soil determined the chosen construction method.

Construction Method. The modified shotcrete tunnel method with partial drivings was chosen as construction method for that 282 m long part of the 1,886 m long tunnel to be constructed in mining technique. The vault was excavated along the entire tunnel length under the protection of a progressing support which consisted of overlapping jet-grouted roof covers of 14.5 m length (fig. 4). The construction of the in total 26 roof covers was done in simplex-jet-grouting method. Each roof cover consists of 39 columns with a minimum diameter of 60 cm.

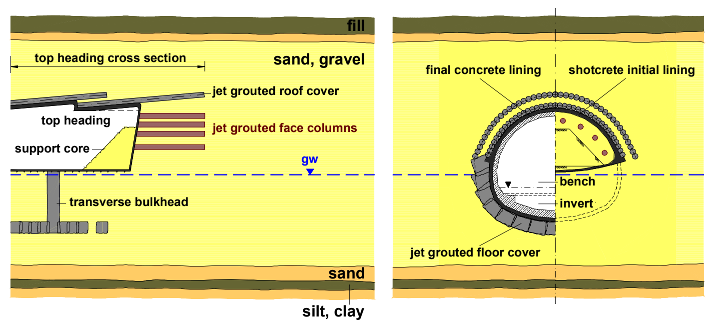

Fig. 4. Longitudinal and cross section, construction details.

After completion of each jet-grouted roof cover the vault was excavated on a part line of 10.8 m. The length of excavation steps were never more than 1 m. Then a new roof cover was grouted. The stability of the face was ensured by the support core and by eight horizontal jet-grouted face columns. On the basis of stability considerations (failure against heaving) the vault had to be stabilised with a closed invert. As the groundwater was not permitted to be lowered sufficiently the excavation of bench and invert took place under the protection of a jet-grouted water tight invert cover. This invert cover, which was subdivided by several bulkheads, consists of a total of 5.900 columns constructed in duplex-method with a diameter of 1.5 m. The construction parameters of the jet-grouted columns were optimised in test fields regarding the ensuring of the required minimum diameter even before work was started. In the course of the carrying out of the project extraordinary demands were put on the exact positioning and controlled production of each jet-grouted column in order to rule out any damage in the system. After this the excavation of bench and invert was carried out with an advance per round of a maximum of 2 m.

Geotechnical Monitoring. The excavation of the tunnel Frankfurter Kreuz was accompanied by an extensive geodetic and geotechnical measuring programme both below and on the surface. This apart from the usual measurements of deformation and tension of the shotcrete lining included a permanent control of the surface settlements in the highway area by an electronically controlled, digital measuring system on the basis of motorised levels. By means of this system the deformation in the direct highway area were measured automatically every 20 minutes. In defined measuring cross sections the behaviour of the ground due to the driving was measured by means of extensometer and inclinometer monitoring.

The settlements measured on the surface until the completion of the driving work are listed for the building phases

- top heading,
- construction of jet-grouted invert cover
- as well as the excavation of bench and invert.

The total settlements show an average of about 2 cm (fig. 5).

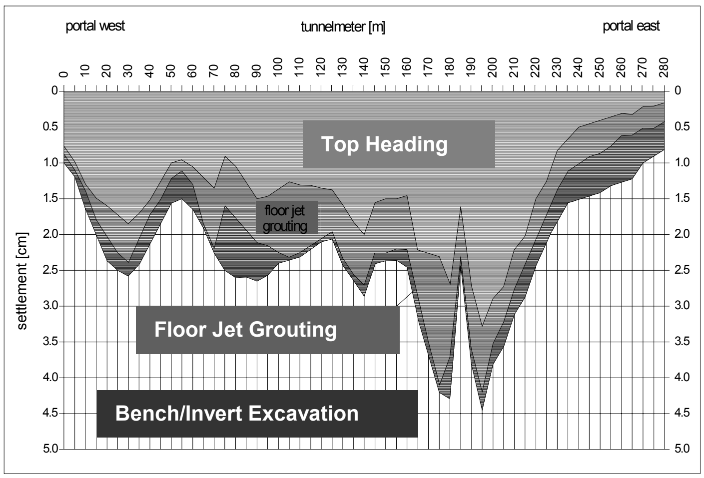

Fig 5. Settlements on surface due to particular construction steps

The maximum settlement added up to 4.3 cm. With a pre-deformation in front of the face of in average 1 cm, the settlements in the tunnel were quite similar to the surface. Up to 60% of the deformation were caused by settlements due to top heading. Another 20 to 30% of the deformation are due to the jet-grouting of the invert cover and the excavation of bench/invert.

4.1.2 Wandersmann-Tunnel North

Ground. With a maximum covering of 20 m the tunnel route lies entirely within semisolid Tertiary clay and mainly below the groundwater level, partly in the area of a landslide (fig. 6). The Tertiary clay can be once more divided in several layers regarding colour and mechanical aspects. The upper layer is about 20 m thick, partly jointed and groundwater bearing. Within this layer obviously local as well as regional sliding mechanisms occurred. A layer of compact, aquifuge clay follows. Sands and marls of the Sonderfacies of the Oligocene underlie this layer with subartesian groundwater level up to 3 m over ground surface.

Construction technique. Due to geotechnical conditions up to 220 m long and up to 22 m deep starting and exit pits on both portals are constructed. The chosen timbering with bored piles (diameter 1,2 m) and several stiffening levels was statically proofed to bear all loads inclusive load resulting from the slide mass. The highway BAB A3 is driven under in an acute angle. The allowed settlements at the surface were limited to 5 cm due to tunnelling. The Wandersmann-Tunnel North was driven with two single-tracked pipes, by means of a shield machine with step-by-step excavation and up to 75 percent mechanical support of the face with steel plates (fig. 7).

Fig 7. Face of the shield machine

The shield diameter is 11,50 m; the preliminary fitting is done with reinforced concrete segments. The final lining consists of a watertight internal formwork. The sliding area itself is secured meanwhile construction phase by a permanent groundwater lowering. After finishing the construction of the tunnels the landslide has been secured with reinforced borepiles in a grid of 5 m parallel and 20 m vertical to the isolines and which are fixed in bedrock ground in a depth of about 8 m under sliding surface. The computing model for securing the slope in this case determined the security against sliding for a well-known sliding mass.

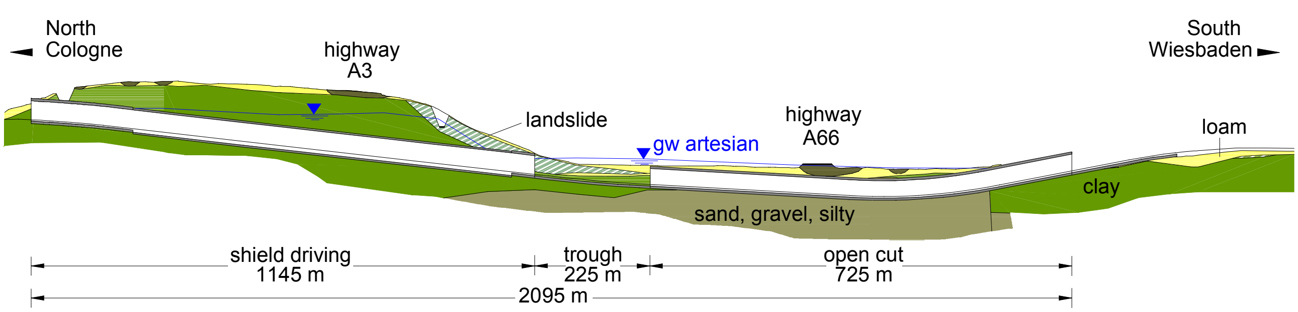

Fig. 6. Geotechnical longitudinal section Wandersmann

4.1.3 Schulwald-Tunnel

With 4.500 m this double-tracked railway tunnel is the longest tunnel of the new line Cologne-Frankfurt. For a detailed prognosis of the ground an intensive exploration programme was carried out.

Ground and Groundwater. The Schulwald-Tunnel is situated at the south-eastern edge of the Rhenish Massif within a tectonic transitional zone between the Upper Rhine Graben and the Lower Rhenian Depression. In the southern part the tectonic transition to the Upper Rhine Graben is tunnelled through. The rock is characterised by an intensive change in lithology of week and hard phyllites. They are deeply weathered and tectonically heavily stressed within the entire area of the line. In the southern part of the Schulwald-Tunnel Tertiary sands are predicted to be only a few meters apart from the tunnel roof. In the north there is a stratigraphic transition up to entirely weathered sericite gneiss. From laboratory testing the phyllites are to be announced as soft rock with unconfined compression strength of 5 MPa in average, but not exceeding more than 10 MPa.

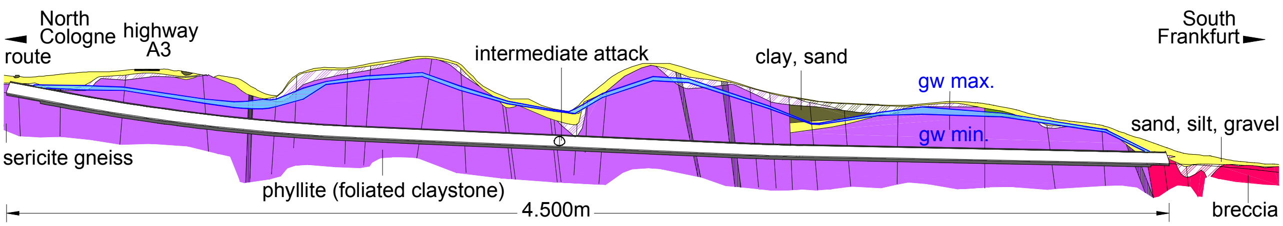

Figure 8. Geological longitudinal section, Schulwald-Tunnel.

Parallel to the line quartz-filled, water-conducting tension fractures are striking. The groundwater level is at a maximum of 51 m; the greatest covering of rock is 60 m above the tunnel roof. The ribbon in figure 8 shows the variance of the highest and lowest groundwater level measured during the controlling period.

Construction Techniques. The double-tracked Schulwald-Tunnel with a full section of about 156 m² is constructed in shotcrete tunnel method with partial drivings. There are 4 starting points available. The particular excavation steps are shown in a longitudinal section in figure 9.

A pilot tunnel (clear section ≈ 30 m²) hurrying on ahead is constructed from the starting points and within difficult rock areas. From time to time this pilot tunnel is once more divided into an upper and a lower half due to major stability problems of the face within totally weathered and intensely stressed rock. The crown area has to be secured by 12 m long injection fore-piles with 4 m overlapping length. In weak rock areas the immediate support is strengthened in general. The shotcrete invert lining of the pilot tunnel as well as the invert lining of the crown are rounded out deeply.

Depending on the results of the geotechnical monitoring the bolting of the pilot tunnel is stretched up to 12 m long injection bolts. These bolts are reused after widening of the crown and are integrated in the systematic bolting of the crown. The effect of this measure is to create an immediate support of the crown resp. of the rock-bearing ring. Due to the results of geotechnical mapping and monitoring of the pilot tunnel after widening of the crown the crown feet in some cases are constructed with a width of up to 1,4 m. However, these widened crown feet can be supplied with an invert lining, if deformation exceeds previously determined limits. The driving is carried out with continuous groundwater lowering resp. -relaxation hurrying on ahead.

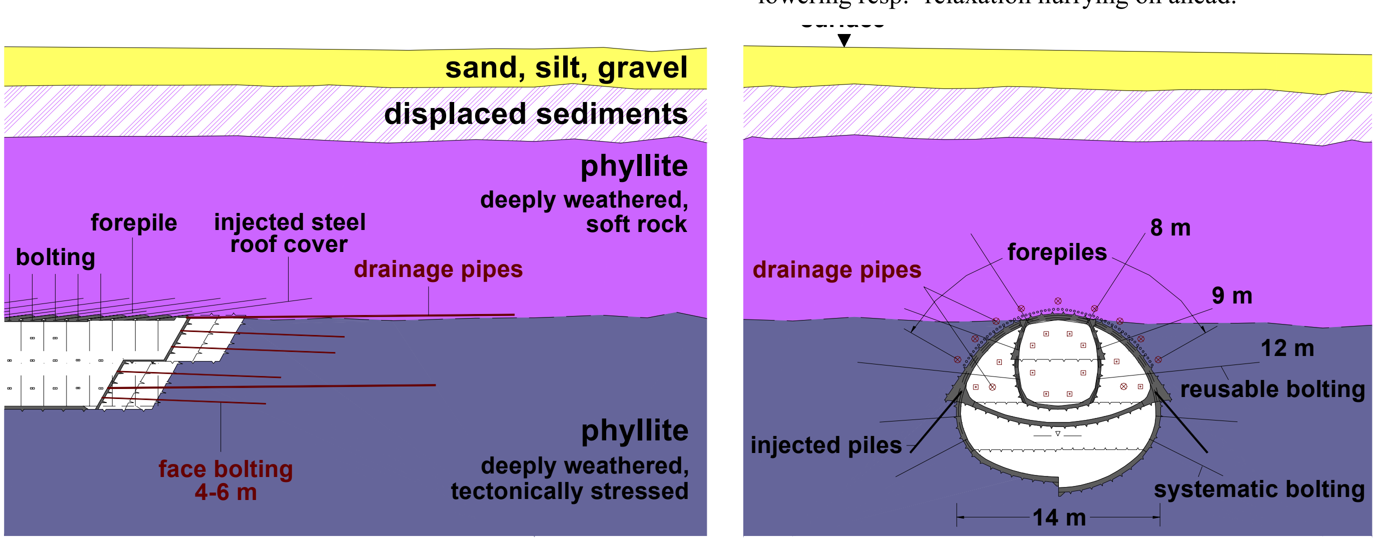

Figure 9. Particular excavation steps, longitudinal and cross section

Geotechnical Monitoring. The excavation of the Schulwald-Tunnel was accompanied by an intensive geodetic and geotechnical measuring programme below and on the surface. Settlements and convergence within the tunnel were measured in permanent distances (25 m - 50 m) and are supplied by further measurements, e. g. in the course of tunnelling through fault zones. In defined cross sections the behaviour of rock due to excavation has been measured by means of additionally installed pressure cells within the preliminary shotcrete lining as well as by extensometer monitoring. All data were available on-line. The behaviour of the more weathered ground in the north and of the more tectonically stressed ground in the southern section is quite similar regarding pre and posterior deformation. At a distance of about 20 m ahead the pre-deformation due to pilot tunnel excavation can be noted. The pre-deformation due to widening of the crown begins at a distance of 10 m ahead.

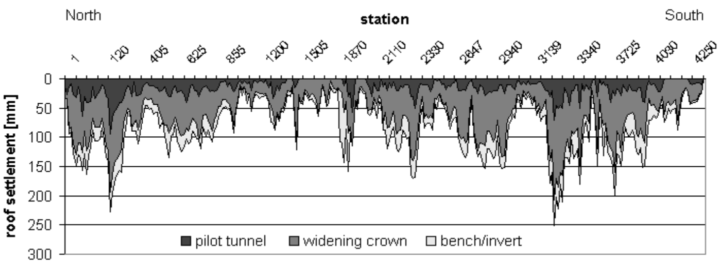

Figure 10. Roof settlements due to the particular excavation steps pilot tunnel, widening to full section of the crown and bench/invert excavation.

Deformation. In figure 10 the results of roof settlements of the driving are shown for the three main construction steps. Slight differences regarding time-settlement behaviour of the mainly weathered phyllites in the northern section and the mainly tectonically stressed phyllite in the southern section of the Schulwald-tunnel are to be noted. Both drivings are excavated under equal conditions regarding overburden and excavation class. In general following major results can be noted:

- The roof settlements due to the driving of the pilot tunnel are very low
- The main deformation arises in the course of the widening of the pilot tunnel up to full section of the crown resp. due to the top heading
- The deformation resulting from bench- and invert excavation are low
- The total deformation do not exceed 25 cm roof settlement at maximum (southern driving), in average 12 cm to 14 cm.

Numerical Considerations. Numerical calculations are necessary to define the design of the tunnel for the construction progress and the final state. Possible deformation and resulting requirements prior construction are to be carried out. The additional support during excavation (e. g. anchoring of the face, roof bolting, roof shelters or injection borepiles in the crown feet) in order to secure the face or to minimize deformation is usually applied without calculation, but strongly on the basis of the deformation behaviour of the ground that is controlled by measurements. The deformation behaviour of the ground is numerically simulated and evaluated on the basis of the ground and groundwater conditions that were encountered and on the basis of the measured deformations, taking the interaction of the sequential excavations into consideration. The two-dimensional numerical calculation method considers the pre-deformation in the face area as a result of the introduction of a pre-relieving factor with the supporting core method (fig. 11).

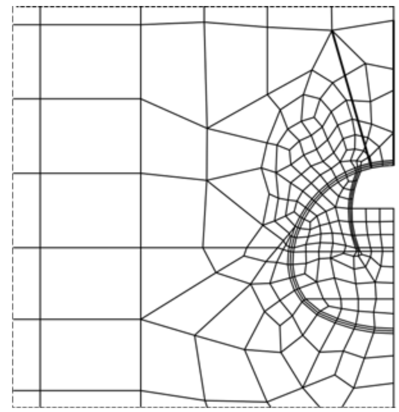

Figure 11. Computational model, simulation of excavation steps

Modelling parameters such as e. g. mesh design, construction sequence, support and securing elements and applied stress-strain laws as well as initial parameters such as Poisson's coefficient and the coefficient of earth pressure at rest are investigated to determine their involvement in the deformations. The results of the computational calculations thus obtained are compared with the results of the geotechnical monitoring during tunnel driving. In a three-dimensional computational calculation, the spatial bearing and deformation behaviour is presented taking particular account of the excavation phases in the ground (fig. 12) .

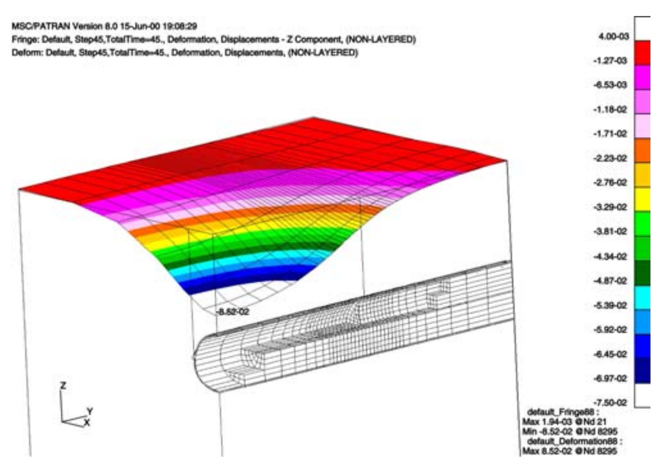

Figure 12. Three dimensional Finite-Element calculation simulation of excavation steps

4.1.4 Siegauentunnel

The 2,5 km long Siegauentunnel has to undercross several buildings, one of them is an old church, in loose ground. The clearance between the foundation of the buildings and tunnel's roof is about 12 m. Because of the geotechnical conditions several driving and securing concepts have been carried out. A pilot-tunnel hurrying on ahead was constructed in pipe tacking technique. Depending on geotechnical situation from this pilot tunnel either groundwater lowerings with wells in distances of about 2 m or roof shelter sealing systems were installed. The universal driving using shotcrete as preliminary outer lining is subdivided in partial drivings; in this case side wall drifts hurrying on ahead. Because of a very inhomogeneous, saturated ground several techniques have been applied in order to guarantee the stability of the face and to minimize settlements at the surface.

The altogether 2202 m long Siegauentunnel can be subdivided in several construction sections and applied tunnel techniques:

Northern section: 585 m open cut
Driving section: 370 m shotcrete tunnelling, thereof 170 m compressed-air driving
Southern section: 247 m open cut

The Northern and Southern section of the tunnel have been constructed in open cuts, partly the door frame slab method has been applied in order to undergo a highway.

Ground. The clearance between the ground surface and tunnel's roof is about 12 m. In general the ground can be subdivided in two main geological units (fig. 13):

- Quaternary sands and gravels
- Tertiary channel filling (fine gravel, sand, silt, clay) basement layers (sand, silt, clay)

The loose ground contents widespread distributed humic portions and organogenous soils, especially within the Tertiary basement layers. The channel filling consists of more than 40 different soils and hence is characterized by anisotropic vertical and horizontal groundwater permeabilities.

The Quaternary groundwater level is near at the surface, the river Sieg nearby. In the following a description of the compressed-air driving and on the results of the geological mapping at this part is given.

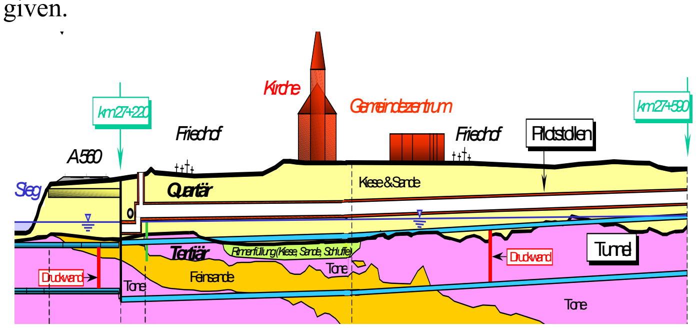

Figure 13. Compressed-air driving section (170 m), simplified documentation of the mapped ground.

Construction technique. The driving was performed on a length of about 200 m in shotcrete tunnelling method with sequential excavation steps, in this case sidewall drifts hurrying on ahead.

The driving was accompanied by a permanent groundwater-lowering hurrying on ahead; because of restricted possibilities to lower the groundwater from the surface (in this area a church with a surrounding graveyard had to be undergone) the driving concept included the following measures:

A pilot tunnel (outer diameter 3.4 m), constructed in pipe tacking technique, runs in a clearance of about 5 m above tunnel roof. From this pilot tunnel a battery of vertical wells in a distance of 6 m and inclined wells in a distance of 2 m discharge the flowing Quaternary groundwater (fig. 14). Furthermore vertical wells were conducted into the Tertiary layer in order to lower this (confined) aquifer.

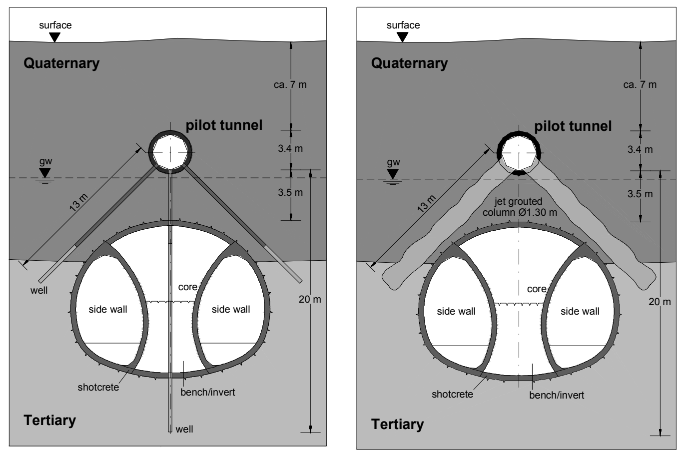

Figure 14. Groundwater-lowering concept, left figure: pilot tunnel with well battery, right figure: pilot tunnel and protection against possible blowouts by jet-grouted roof cover

At station 200 (driving south) the very inhomogenous sediments of the Tertiary channel filling stroke in the tunnel profile and instabilities and cave-ins, accompanied by unexpected groundwater ingresses, occurred. Additional measures such as freezing the ground, further horizontal wells from the face or injections had no effect and the driving failed. The attempt to start a driving from the north failed mainly because of the water-holding capacity of the humic and organogenic soils as well as due to a permanent groundwater-connection between Tertiary and Quaternary layers outside the groundwater-lowering well battery. These soils could not be dewatered sufficiently.

Under respect of these geotechnical conditions the decision was made to change the scheduled tunnel driving concept and to start a compressed-air driving. In order to prevent possible blowouts during the compressed-air driving a 154 m long jet-grouted roof shelter and several bulkheads had been constructed from within the pilot tunnel (fig. 14).

The compressed-air driving itself began with an air pressure of 70 kPa and had to be enlarged up to 120 kPa in areas, where groundwater or instabilities of the face occurred. For the same reasons each scheduled sequential driving step still had to be subdivided in several excavation steps. The driving under compressed-air of the 170 m long section of the Siegauentunnel was completed after about 6 months work successfully.

5 NEW MAINZ TUNNEL

The New Mainz Tunnel (NMT) is part of the extension railway line between the cities Mainz – Mannheim and runs almost parallel to an existing old railway line The distance between the New and the Old Mainz tunnel (OMT) varies between 4 m minimum and 50 m maximum.

Ground. The geological setting is mainly characterised by the Tertiary strata (Miocene) of the Mainzer Basin. The Tertiary strata sequence consists of an alternating sequence of marly clays, chalk marl, sandy silts (hydrobia silts, hydrobia oyster shells) and sands in an alternating sequence with chalkstone banks (fig. 15). The consistency of the in situ ground is stiff to semi-solid, turning into soft/paste-like if water intrudes. The groundwater reaches the level of the tunnel floor.

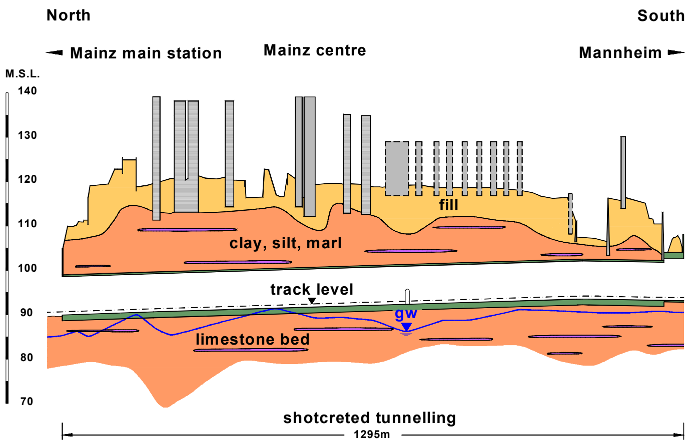

Figure 15. Geotechnical longitudinal section of New Tunnel Mainz

Construction Technique. Regarding ground conditions, existing settlement-sensitive structures and the possible influence on the Older Mainz Tunnel the excavation of the New Mainz Tunnel had to be carried out only with little deformation. Hence, an universal shotcrete tunnelling method with side wall drifts hurrying on ahead and delayed excavation of the calotte and core / bottom was chosen as construction method

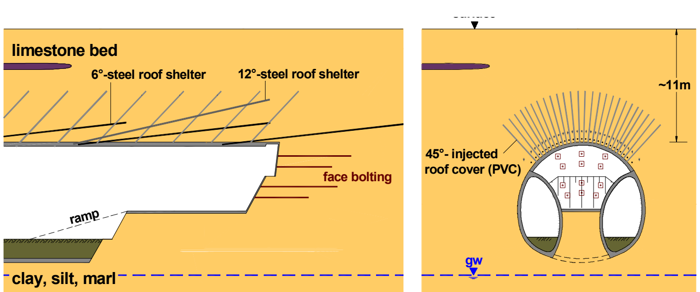

Figure 16. Shotcrete tunnelling with sequential excavation, sidewall, core and bench/invert

The distance between the side wall's face and the external formwork's final ring closure was limited to < 100 m and in particularly sensitive parts to 50 m. The installation of the internal formwork follows in only a little distance behind the external formwork (calotte's heading to finished internal formwork shorter than 120 m). Besides the usual securing measures further securing measures were taken in areas of settlement-sensitive structures. As special measures additional injected roof shelters, injections from the ground surface and injections from the tunnel as well as anchoring of the face have been applied (fig. 16).

The ground covering above the New Mainz Tunnel is relatively small and varies between 10 m - 23 m in general; a street had to be undercrossed with an overburden of only 4 m. Furthermore there are many buildings equipped with basements, e. g. a hotel with a foundation depth of about 8 m – 10 m under ground surface, which have to be undercrossed. Moreover, there are old (Roman) underground hollow spaces (gallery systems) in the overlying ground as well as old walls at the surface.

Geotechnical Monitoring. Regarding the extraordinary situation to undercross several settlement-sensitive structures with only low overburden in soft ground an extensive geotechnical monitoring programme had been carried out. At the surface the deformations due to tunnelling are measured over close distances by leveling as well as deformation monitoring systems, working on the principle of corresponding tubes. The settlements measured at the ground surface were between 20 mm and 40 mm (prognosis 45 mm). The measured deformations within the tunnel, e. g. roof point settlements with up to 10 mm to 15 mm are within the limits of the expected values had a width of about 20 m rectangular to the tunnel axis. With the described tunnelling concept the New Mainz Tunnel was driven under the inner city of Mainz successfully. The settlements on the ground surface remained within the limits of the prognosis.

Figure 17. Side wall drift, picture from site

Numerical Considerations. The behaviour of the ground especially in the area of undergoing settlement sensitive structures was numerically simulated and evaluated on the basis of the ground and groundwater conditions that were encountered and on the basis of the measured deformations, taking the interaction of the sequential excavations into consideration. In figure 18 the 3-D Finite-Element mesh and in figure 19 some results of the numerical analyses are presented exemplarily.

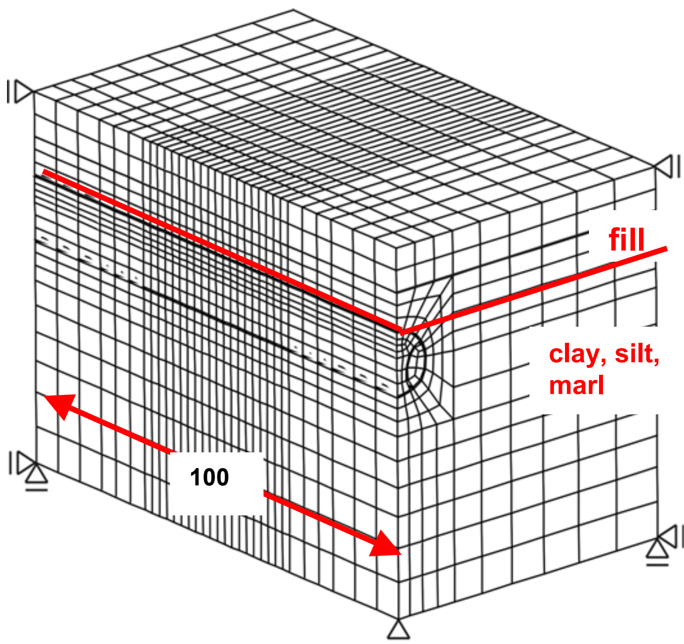

Figure 18. 3-D Finite-Element mesh

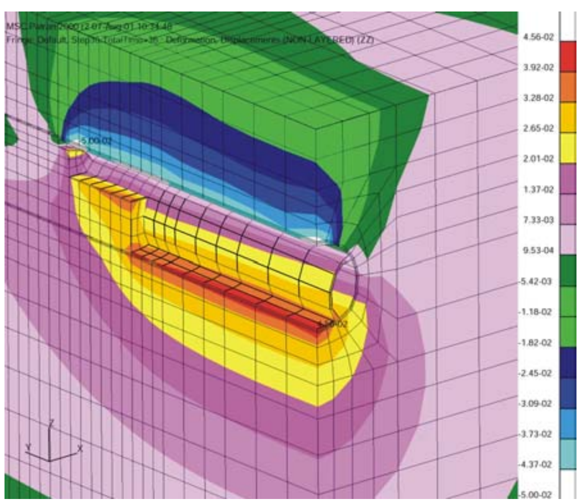

Figure 19. Results of deformation calculation

The good results of these calculations are a excellent basis for the prognosis of tunnelling projects in similar or equivalent ground and groundwater situation.

6 NEW LINE NUREMBERG - MUNICH

The new line runs to a large extent in close bundling with the federal highway A9. On the 89 km long line between Nuremberg and Ingolstadt 7 valley bridges, 38 road bridges and 9 tunnels with an overall length of 26 km are constructed.

<u>Keywords geology.</u> Frankish Alb, Triassic and Jurassic clay-, sand- and limestones, Tertiary and Quaternary loose ground: Limestone and dolomite of the White Jura (Malm), Tertiary and Quaternary loose rock covers

<u>Characteristics</u>. Swelling clays and claystones, Karst/earth drop area, slide slopes, artesian groundwater, earthquake zone 1.

The ground is characterized mainly by Tertiary silts, sands, clay and marls and Lower, Middle and Upper Jurassic rocks. In the middle and southern section of the new line karstifiable limestone and dolomite rocks line up, which are locally and strongly affected by the karstification. The rock conditions are heterogeneous and characterized by karst structures of different kinds which are lined up closely.

Not only the tunnel driving and bedding of the tunnels themselves, but also the foundation of the entire line within these heavily jointed and deeply karsted rocks require additional measures to guarantee the stability and serviceability of the construction. The general knowledge of karst phenomena such as the process of solution of limestone, the evolution of caves and caverns, possible break downs and sinkholes as well as involving risks was specified for the entire railway line. The usual exploration of the ground through boreholes is completed by additional exploration techniques such as :

- historical investigation
- analysis of satellite photo lineations
- analysis of tectonic structures
- hydrogeological tests
- geophysical investigation

Gravimetric, seismic, sonic and geo-electric geophysical investigation methods are applied after checking their reliability in well-known test fields; nevertheless two different geophysical methods are applied in order to use redundant effects. The actual results are proofed through local drillings as well as through the comparison and evaluation of the geotechnical documentation of the drivings. On the basis of all investigations additional measures such as

- specific regulations to avoid negative effects regarding the infiltration of water
- filling of open structures with concrete/cement suspension
- grouting of defined areas up to a depth of 10 m
- foundation of the line on reinforced concrete plates

to secure the construction.

In the context of the investigation besides the usual ground exploration the question of Karst was supplementary investigated by methods such as aerial photograph-supported and satellite photograph-supported evaluation of lineaments or special karst-hydrogeological analyses. Certain data to the amount of the place of occurrence and geometry of Karst caverns or karst structures in general, their rates of refilling or the occurrence of earth falls could not be given despite exhaustion of the investigation techniques at that time from applicable investigation methods. During the driving of the tunnels as well as with the construction of open cuts karst formations of any geometry were found. In the course of the proof of stability and serviceability on basis of intensive national and international literature studies different endangerment pictures were developed concerning possible tasks resulting from the topic Karst.

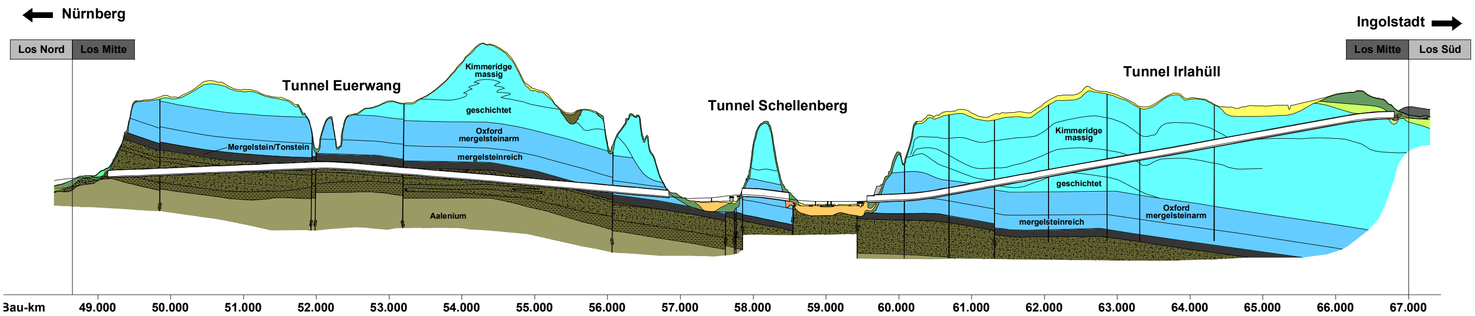

Figure 20. Tunnelling through Karst,, right part of the longitudinal section Tunnel Irlahüll

Additional computations were accomplished regarding the possible sphere of influence due to Karst or earth falls. Whereupon extensive investigation measures (geophysical procedures, ground exploration drillings) in already driven tunnels and within the range of the foundation levels of cuts, dams and retaining structures were fixed and carried out. The results of these accompanying investigations made design and execution of counter measures such as stabilizations with grouting and constructional solutions at the construction possible.

The example Karst points out impressively that well-known geological phenomena e.g. the karstification in contractual sense only reduced qualitatively and still less quantitatively the necessary description to minimize ground risk. Under valuation of the requirements of stability and serviceability of the building and the requirements and criteria for the installation of the rigid track possible endangerment pictures on the basis of accompanying investigations, computational investigations etc. must be evaluated as comprehensively as possible and be discussed in the sense of a view of remaining risk with the owner of the line.

The effects of Karst e.g. open caverns on the tunnels and on the foundation of the railway line have been examined in detail by various numerical analysis. As a result of the entire examinations various measures and techniques have been applied depending on the geometry and size of open structures or possible sinkholes to secure the construction and to guarantee the serviceability of the construction.

7 EXTENSION AND NEW LINE KARLSRUHE - BASEL

Between Karlsruhe and Basel at present only the double-tracked Rhine Valley course (Rtb) is available for the north south traffic. By the expansion of the rail traffic in the neighbouring countries an increase of traffic is to be expected for the Rhine Valley course. In order to increase the capacity for the passenger and cargo traffic and to reduce the travel time in long-distance traffic (higher driving speed) a 4-tracked development of the existing line between Karlsruhe and Basel is planned. Within the range of Freiburg a double-tracked cargo line is to be built parallel to the highway BAB A5.

Keywords geology. Rhine Valley, Metamorphite, Mesozoic rocks, Tertiary vulcanite, Quaternary clay, silt, sand and gravel

Characteristics. Drinking water protected zones, soils with organic components, slide slopes, groundwater level, mining industry, stores, earthquake zone 1-4

The most challenging tunnel construction of this line will be the more than 9 km long Katzenberg-Tunnel that will be driven with a tunnel boring machine mostly in Mesozoic rocks. Hard soils and soft to hard rocks that a partly karstified have to be tunnelled through.. The design of the machine is on the run, the driving will start in the very close future. Possible interactions due to tunnelling with well-known sliding areas have to be checked by numerical analyses.

The about 2,200 m long Tunnel Mengen (fig. 21) has to undergo a gasoline station with only little covering. The ground consists of a silty sand (loess) which reacts in a very sensible manner to the appearance of water by changing its consistency. At the moment feasibility studies are carried out to determine the applicable tunnelling technique that guarantees the minimum of impairment on the gasoline station.

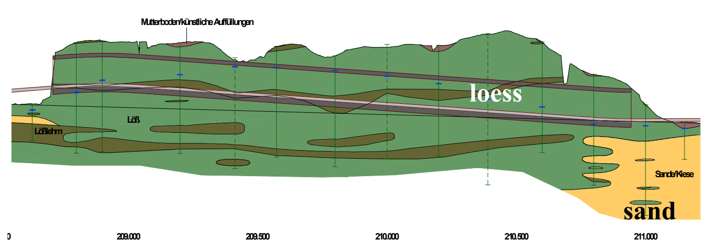

Figure 21. Longitudinal geological section Tunnel Mengen

8 NEW LINE RHINE/MAIN–RHINE/NECKAR

The planned line between Frankfurt and Mannheim is planned as a double-tracked line for high-speed traffic. A study that has been accomplished between the state Hessian and the Deutsche Bahn AG pointed out that a development from two to four tracks is not reasonable for the in this region existing older lines. Therefore the new route runs as close as possible to the federal highways. At present the regional planning procedures are carried out in the state Hessian and Baden-Wuerttemberg.

Keywords geology. Rhine Valley, Quaternary clay, silt, sand and gravel
Characteristics. Drinking water and protected areas, soils with organic components, groundwater level, stores, earthquake area

The planned tunnels will probably be driven in open cuts, in some sections the doorframe slab method will be applied. The decision to construct the new line is on the run.

9 GENERAL REMARKS

The decision to apply a tunnelling technique is based on the geotechnical conditions and numerical considerations first, but also on conditions given by certain circumstances such as authority regulations, tunnelling under built-up areas and of course by means of costs. The geotechnical conditions are evaluated on the basis of investigations of ground and groundwater. Investigation measures before beginning of construction are to describe the ground so completely that the contractor's knowledge regarding geotechnical information and data as the basis for his calculation is sufficient. If this is not possible, the owner together with the geotechnical expert, should accomplish if necessary a distribution of risks analysis, should discuss possible ground risks and their contractual consequences and should point out further investigation measures, which are purposeful due to the structural boundary conditions during the execution of construction only. Regarding this, contractual regulations are to be made. Furthermore a design planning co-ordinated on the basis of the results of the accomplished ground investigation should be taken as a basis for the building contract. The description of the ground must at least cover the DIN 4020 and the aspects of geotechnics represented in the Deutsche Bahn-internal sets of rules. Constructing must refer promptly to well-known or recognizable risks and/or typical problem definitions and submit first suggestions on the building ground investigation program.

The design of the tunnel is based on the geotechnical prognosis (ground model, groundwater situation, soil- and rockmechanical parameters) by numerical analyses in order to guarantee the stability and serviceability of the construction.

The evaluation and determination of the interaction between ground/-water conditions and the applied tunnelling technique as well as the interpretation of geotechnical monitoring are main challenges to tunnelling besides a good workmanship.

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