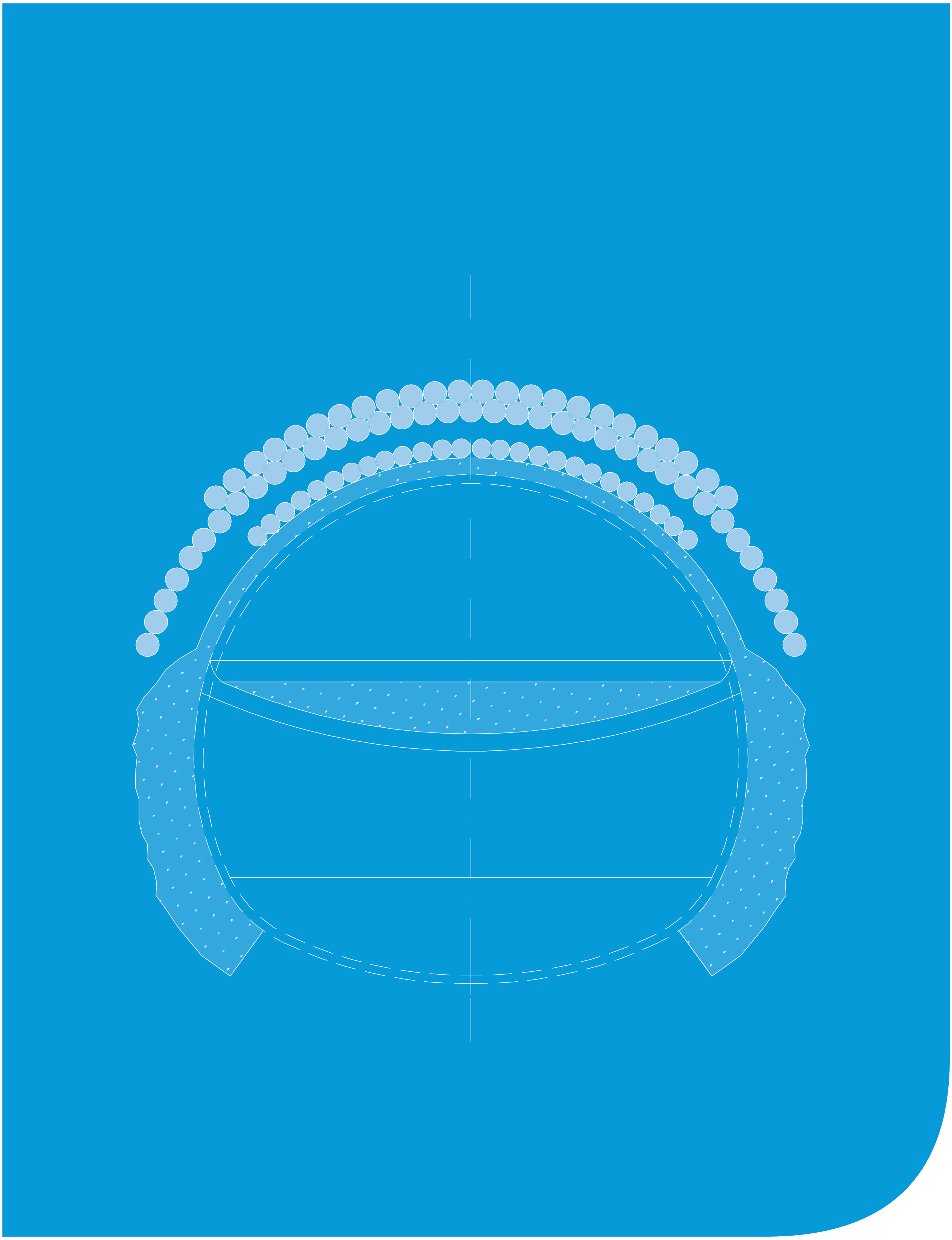
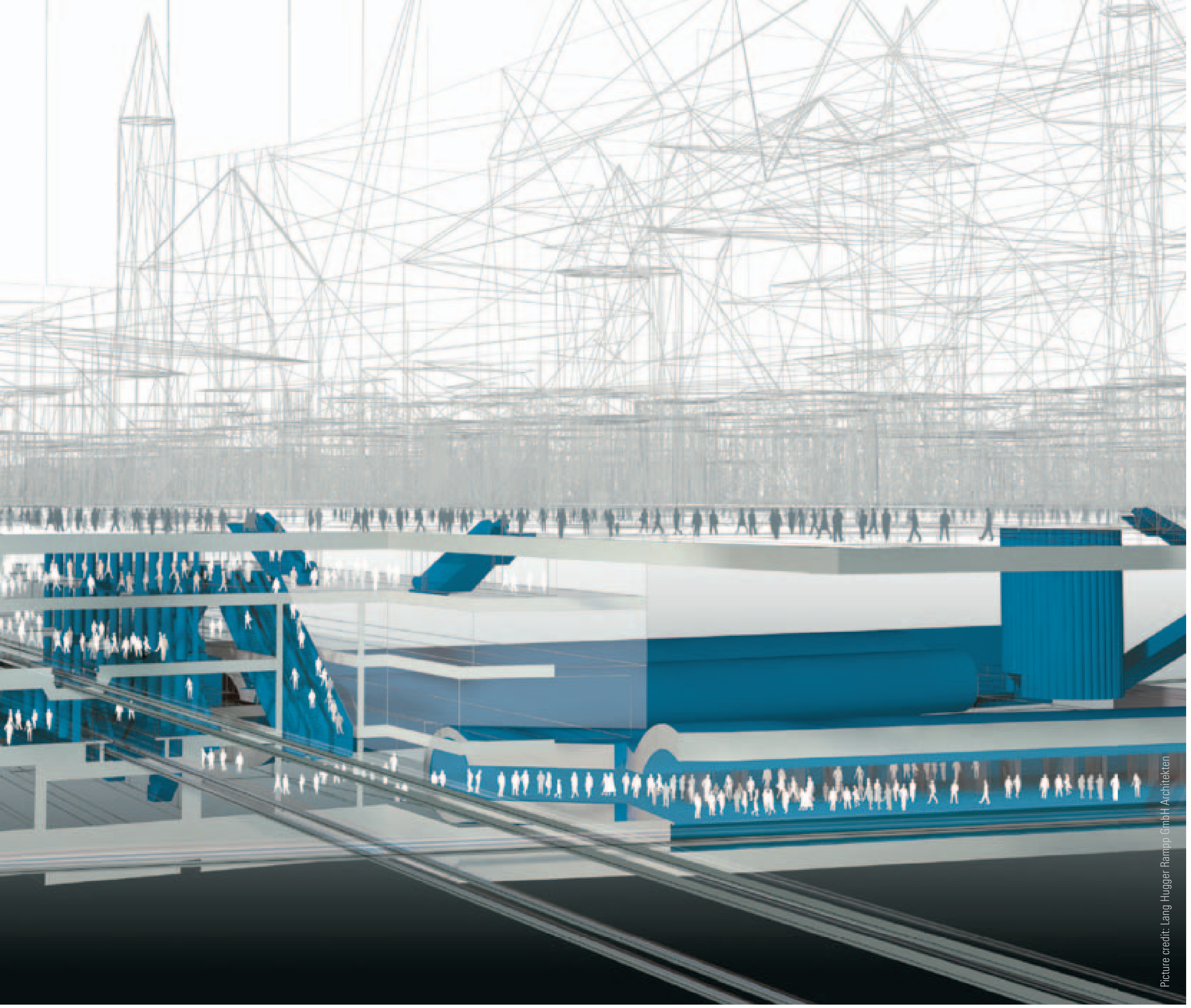
German Tunnel-Expertise Group

Conventional Tunnelling / Shield Tunnelling / Shafts / Caverns

Expertise Group for Planning – Structural Analysis – Development – Consultancy





Metro station Marienplatz – railway connection in the centre of Munich - visualisation

Tunnel construction is one of the most interesting yet most difficult disciplines of civil engineering. It combines theory and practice to form an engineering art of its own, requiring wide-ranging knowledge and long years of experience in the fields of civil engineering, structural engineering, geology and hydrogeology, geotechnics as well as mechanical engineering and construction methods.

Introduction

Constantly increasing traffic in urban conurbations and at the same time limited availability of traffic surfaces, growing requirements of regional and national traffic networks and mobility and last but not least the demand for protection and conservation of living spaces underline the importance of underground construction. The technological complexity of tunnel construction projects, especially in inner-urban area, is one of the greatest challenges of civil engineering. Interaction between ground and tunnel drilling as well as resulting surface settlements and building displacements are to be managed and minimised. The German Tunnel-Expertise Group is an association of SSF Ingenieure AG, K+S Ingenieur-Consult GmbH & Co. KG, Baugeologisches Büro Bauer GmbH and Technische Universität Munich, Institut for Engineering Geology with first rate experience in tunnel and metro infrastructure.

An interdisciplinary team of experts working in partnership and applying an integrated multi-disciplinary approach to resolve tomorrow's tunnel issues today. The members of German Tunnel-Expertise Group are specialists in planning, design and management services for tunnels, metro infrastructures, deep foundations, excavations, support structures and ground improvement. Our teams are at the forefront of ensuring a comprehensive approach, fostered by a partnering culture. Thanks to close collaboration within the partners' companies, the association delivers holistic solutions for major infrastructure projects. The comprehensive knowledge and understanding of the interaction of numerous factors when it comes to implementing underground construction sites and their interfaces enables us to optimally assist you during all stages of a tunnel project.

The team of the German Tunnel-Expertise Group specialises in applying comprehensive knowledge and long years of experience in the field of underground construction by intensive interdisciplinary dialogue in order to optimise projects as a whole. The assessment of execution, cost and schedule risks and unpredictability of complicated and difficult conditions are part of our services too, as well as the adaptation of the design to expedient and efficient practicability on site.

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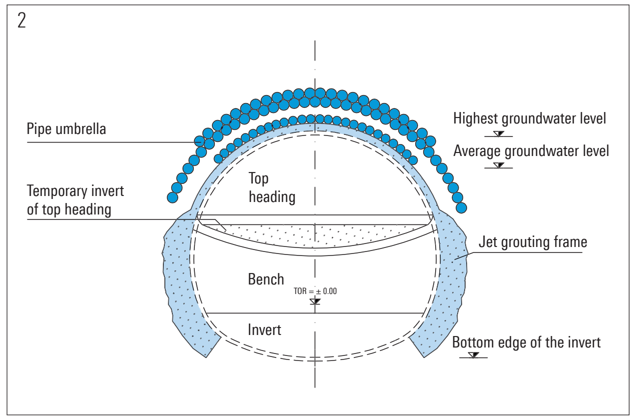
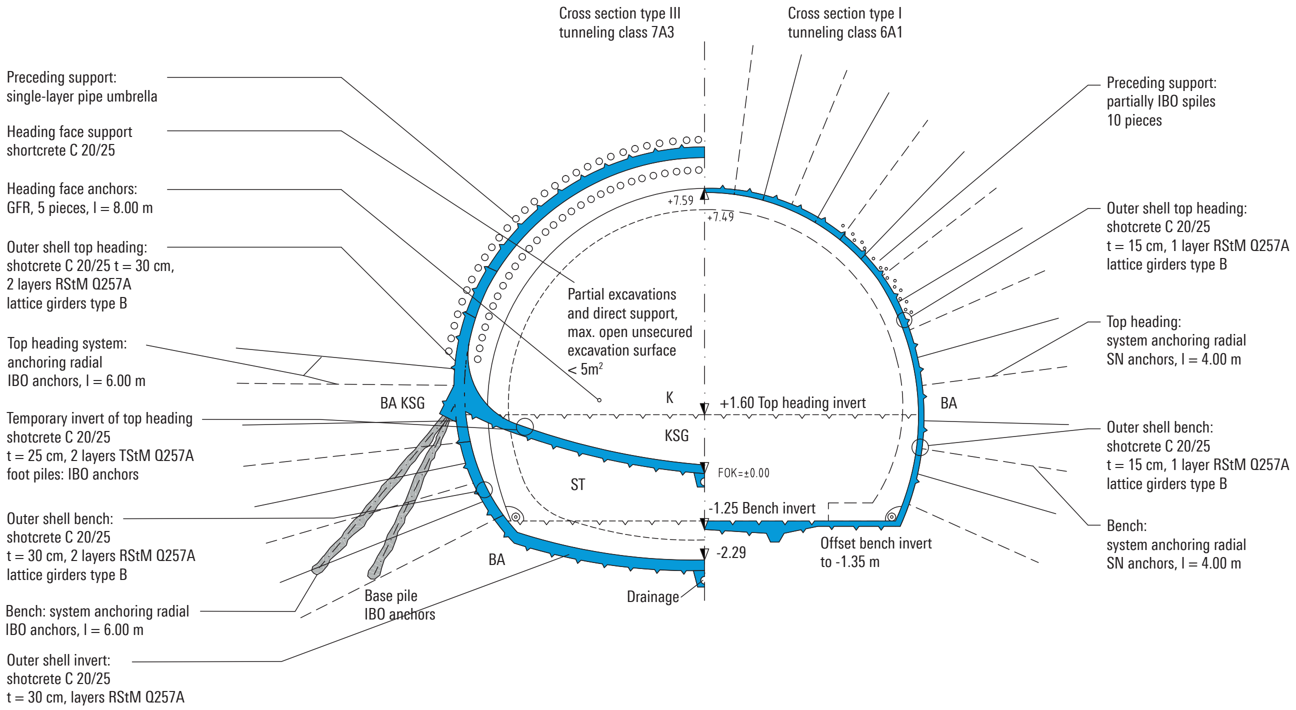


The range of expertise in mechanical and conventional tunnel construction includes:

- ground modelling and assessment
- feasibility studies
- selection of optimum tunnelling method
- launching and receiving procedures
- tunnelling simulations
- selection of securing methods
- lining classification
- supporting pressure calculations
- non-linear geotechnical FEM analyses and settlement prognoses
- performance and wear prognoses
- dimensioning of final linings
- structural analyses
- tunnel segments design
- fire protection analyses and concepts
- drainage concepts
- analyses of rock face and earth slope stability
- monitoring /surveying programmes
- evidence preservation
- geological and geotechnical consulting/construction management
- target /actual comparison
- cost and schedule assessment
- contract and cost management
- construction management and supervision
- project management
- analysis of construction interruptions
- error and risk analyses
- gallery structures for stations
- underground caverns
- cross-cuts
- tunnel grouting
- excavation /undercutting /underpinning
- supplementary measures /ground improvement
- bored piles, diaphragm or temporary walls
- back anchors and rock anchors
- tunnel renovation
- concepts for technical tunnel equipment

1 **Tunnel Jin Shazhou China,** drill & blast method, phase topheading with enhanced temporary lining

2 **Conventional excavation,** divided in top heading, bench and invert, top heading advance with compressed air protected by a pipe umbrella and lateral soil improvement in the area of the tunnel side walls, construction of a bench and invert with pressure level of 1.1 bar, protected by 30 cm thick shortcrete



Two cross section types for cyclic tunnelling, representation of support devices for different tunnelling classes

Ground Modelling

Tunnelling projects present from the beginning huge challenges in view of geological matters. The so-called 'view into the dark', the unknown of the ground has to be understood to be calculable. The knowledge of the ground is decisive for all stages of design and construction to obtain a sustainable, economic, safe and well-developed solution.

Especially for financial reasons, it is sometimes only possible to carry out selective spot check investigations and then to analyse conscientiously this small 'insight' into the ground in order to elaborate reasonable definitions and identify geotechnical homogenous areas.

Ground modelling requires in addition to a thought-out, locally adapted investigation programme, the integration of knowledge regarding the geological genesis. Only in this way functional parameters can be developed, substantial estimations for design, calculation and implementation be made and geological key problems be identified and evaluated. It is seldom sufficient to meet standard requirements as always individual project-specific questions are to be answered, where the structure/geology interaction plays a significant role.

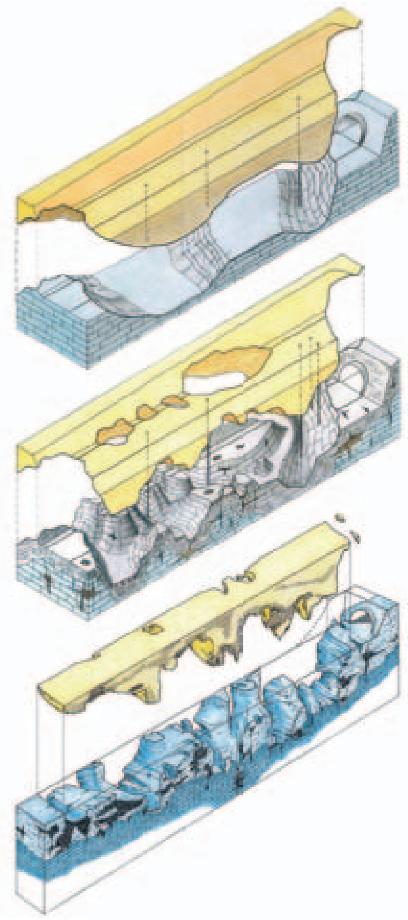
Investigation, Methods and Programmes

Changing direct and indirect exploration methods result in economic solutions and lead to comprehensive knowledge of the hydrogeology and geotechnics. Moreover, an additional laboratory programme forms the basis to establish geotechnical parameters.

Direct exploration methods:
- investigation drillings of surface (vertical / oblique)
- investigation drillings of tunnel (radial / preceding)
- diggings
- exploration tunnel / pilot drillings
- groundwater measurement points and gauge

Indirect exploration methods:
- dynamic probing (DPH-DPL)
- cone penetration test (CPT)
- geophysical procedures
- documentation of washed material during anchor drillings/pipe arch construction and injections
- documentation of excavated material during mechanised shield tunnelling
- extensometer / inclinometer / piezometer

Laboratory analyses:
- composition of mineralogy and form
- pore spaces / mineral bonding
- rigidity/compactness / consistency
- compressive, tensile, shear resistance
- compression behaviour, plasticity and elasticity
- abrasiveness and adhesion



Metamorphosis of the ground by high temperature and pression – Exemplary representation of a ground model from a simple use of investigation data to a detailed geological model

Knowledge of Geological Genesis

The geological model has to be based on investigations and knowledge of the geological genesis to be able to define geological boundaries. Tectonics and erosion processes influence the original horizontal compactness of sediments. Chemical, physical or biological processes such as weathering or hydrothermal energy can lead to changes of geotechnical parameters. Ground formation processes generate geotechnically decisive intermediate layers. Magmatic intrusions are vertically relevant and metamorphic transformations influence compression and temperature. Primary anisotropies and inhomogeneities have an effect on all of these processes.

Geological and Geotechnical Key Problems, Recording and Evaluation of Risk Potentials.

A detailed ground model indicates possible hydrogeological key problems and allows an evaluation of relevant risks. Discontinuities such as clefts and faults, unclear demarcations between solid and unconsolidated rock material (mixed-face conditions), changeable solid rocks, abrasiveness, adhesion potential, hydrological separating layers, secondary changes such as cavities or backfills, but also anthropogenic interventions can be problematic and have to be taken into consideration when choosing excavation and support methods.

Conventional tunnelling allows local adaptations of tunnelling and lining classifications, when using tunnel boring machines with tunnel lining segment lining the whole range of rock parameters has to be taken into account.

Local aquifers, undiscovered during investigation and whose water could be under pressure, as well as cohesionless, water-saturated backfill can be risky.

Hydrogeological / Geotechnical Documentation

No preliminary investigation can detect all eventualities and predict an exact distribution of rock material. For hydrogeological and geotechnical consulting a geological-geotechnical documentation is of great importance.

Direct explorations such as heading face cartography, additional investigation drillings, and findings from indirect procedures such as documentation of washed and excavated material make the generation of three-dimensional ground models possible and thus the definition of rock units. The documentation of their characteristics and formation, their degree of weathering and fracturing, their location and water content as well as their rock behaviour serve to optimise the model and hence improve risk estimations.

The German Tunnel Expertise Group has wide-ranging experience in ground modelling. From first investigations to final handling of tunnel projects, technical conclusions can be drawn from geological/geotechnical prognoses and documentations. The interdisciplinary comparison of investigation and tunnelling data enables us to optimise the model during early stage and to deliver geological and geotechnical consulting.

Tunnelling Methods

The selection of the tunnelling method depends on project-specific boundary conditions. Ground, length, cross section, use and location of the planned tunnel are the first essential criteria to be taken into consideration in view of technical feasibility and economic efficiency.

Tunnelling methods	
Machine tunnelling	- tunnel boring machine in solid rock - shield tunnelling in unconsolidated rock
Conventional tunnelling methods	- tunnelling excavator - roadheader - drill & blast

Further divisions of tunnelling methods are regulated in national European standards.

1 **Heading face documentation** on the example of the Brenner Tunnel H5, lower Inn valley, excavation cross section 125 m², l = 8 km, conventional tunnelling method, drill & blasting, excavator

2 **Tunnel boring machine (mixed shield):** Tunnel Cologne, North-South-Line underground railway, outer diameter = 8.40 m, tunnel length = 5.4 km, 8 stations

3 **Conventional tunnel excavation** with a pipe arch construction (l = 10 m, d = 150 mm), Birgltunnel (l = 960 m, cross section = 120 m²)

4 **Regular cross section of shield tunnel for** road traffic, separated tunnel galleries (inner diameter 11.0 m) with cross-cut/connecting gallery (inner diameter 5.52 m) arranged every 500 m as per RABT standard and 'Regulations for fire and catastrophe protection for construction and operation of railway tunnels' of EBA (German railway authority), Tunnel Sucharski Gdansk/Poland l = 1.175 km

Shield tunnelling

Highly mechanical tunnelling methods such as earth pressure balanced shields and hydro shields in unconsolidated rock are employed with temporary support of the surrounding ground by soil or bentonite suspension and a shield skin. In solid rock, special rock drilling heads are used. Depending on the compressive resistance of the rock, cutting devices such as scraper tools, disk cutters or rippers remove the ground or break it into conveyable chips. Within the shield skin, the final lining in form of prefabricated reinforced concrete tunnel lining segments is installed. In order to guarantee a durable, tight tunnel structure, high demands are placed on design and dimensional accuracy of the tunnel lining segments.

Conventional Tunnelling Method

The right choice of support measures is of utmost importance for safe underground tunnelling as well as for securing buildings and other installations above ground. For conventional tunnelling with excavator or by blasting or with roadheader, a reinforced shotcrete support, spiles or system anchors are the traditional support measures. In critical areas heading face anchors, pipe arches, multi-divided cross sections and base enlargement are used. The inner shell to be constructed block by block afterwards forms the final lining.

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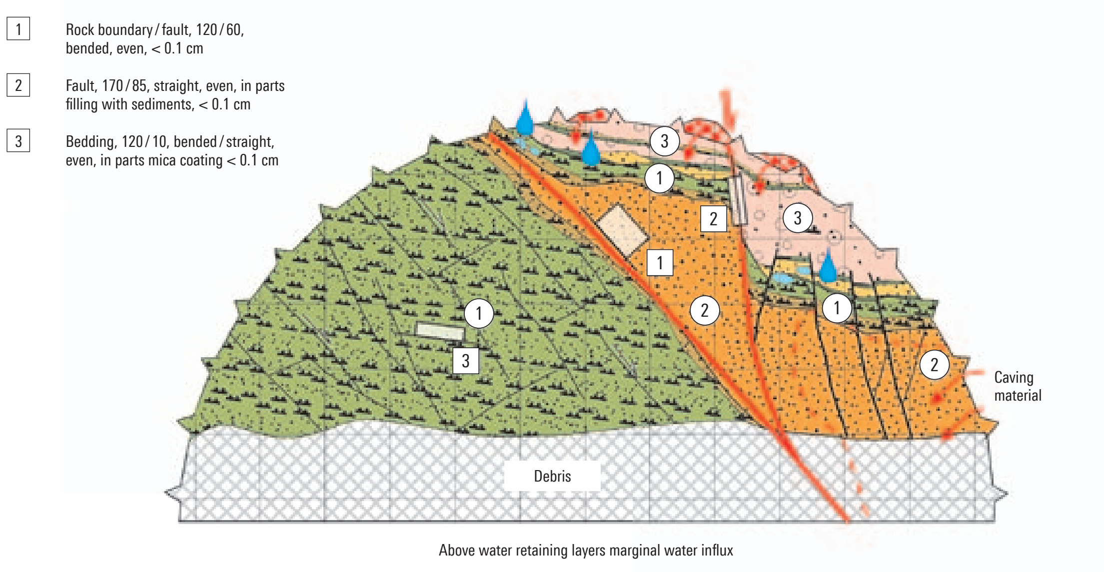

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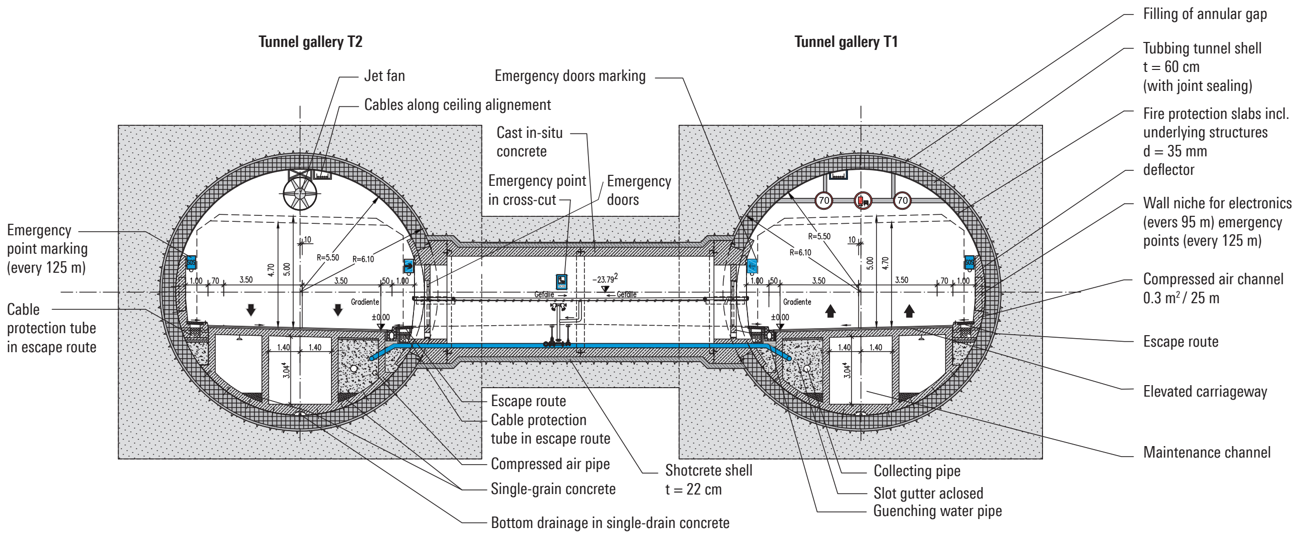

Compressed Air Tunnelling

The design of compressed air tunnelling is based on geological and hydrological parameters as well as on technological tunnelling procedures. Groundwater levels, porosity and fractures (open separating surfaces) of the rock as well as effective intermediate layers have to be taken account as well as excavation cross section, tunnel length, construction and time and adapted construction logistics.

For the calculation of compressed air losses and thus the design of the whole installation (compressors, water pipes), a decisive role is played by the lock, the shotcrete quality, the open surfaces at the heading face but also additionally installed sealing systems such as diaphragm walls. All works have to be delivered in accordance with DVO (German regulations for works under compressed air).

The use of compressed air has to be controlled continually, and water levels and deformations have to be measured regularly to detect blowouts and avoid a collapse of the sensitive support system. The used machines, construction process and logistics are to be taken into consideration from a technical point of view, because, as soon as the working chamber is under pressure, all materials have to be brought in or out via the lock.

The shotcrete method is, from a geometrical point of view, a very adaptable tunnelling method. The temporary shotcrete shell can be adapted at short notice to alternating ground conditions, e.g. by arranging an invert, varying the shotcrete's thickness with single or double-layer reinforcement or dividing the excavation cross section. The possibilities range from a thin, flexible shotcrete shell when constructing a load-bearing ring to a thick, bending-stiff shell when the construction of a load-bearing ring cannot be guaranteed or the requirements of tunnelling with low settlements are even higher. The reinforcement of the shotcrete shell is defined, in addition to geotechnical boundary conditions, by the cross section form and bending stiffness of the shell.

Opening and Construction of Cross-Cuts

A cross-cut is a connecting structure between two tunnel galleries or from one gallery to a shaft structure. Depending of the boundary conditions of the individual project and in particular the tunnelling method of the main tunnel, geometry and construction method of the cross-cuts vary. 3D calculations represent realistically geometry and settlement behaviour as well as complexity.

All construction stages, beginning with the opening of the tunnel lining segments inner shell, to the construction of the connecting structure have to be determined in detail and analysed already during the design process. The construction of a cross-cut underneath the groundwater level or in unconsolidated ground requires supplementary temporary measures such as injections, ground freezing, compressed air or groundwater lowering. We combine realistic calculations of the structurally difficult opening areas with proven knowledge of structurally necessary and economically reasonable construction processes. On the basis of our experience, calculated results are combined with structurally thought-out supporting devices to minimise deformations.

The German Tunnel Expertise Group designs your tunnelling project with regard to requirements of settlement minimisation. We advise you in view of the most appropriate tunnelling method and heading face support, and optimise the type of temporary as well as final tunnel support. With regard to economic efficiency, effectiveness and best practice we deliver structural calculations for standard and special procedures. Calculation results are reviewed by means of deformation measurements with regard to technically safe and economic tunnelling and are adapted if necessary. The widespread practical experience and high scientific competence as well as the use of most modern simulation software tools, showing the effects of supporting measures, are to be emphasised.

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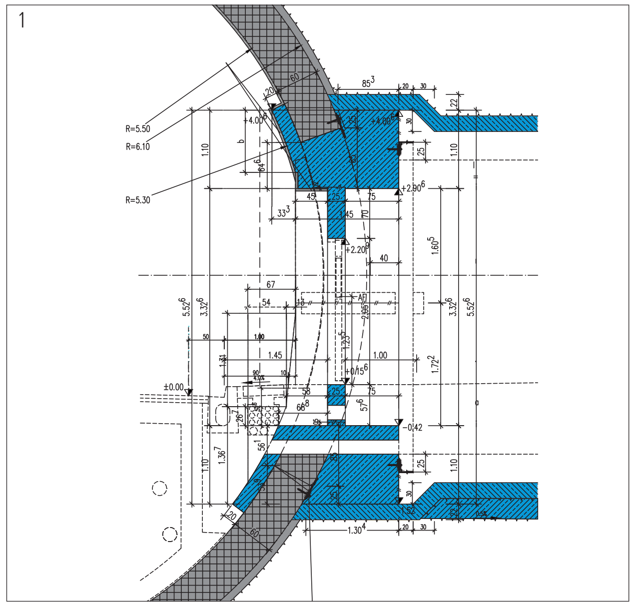

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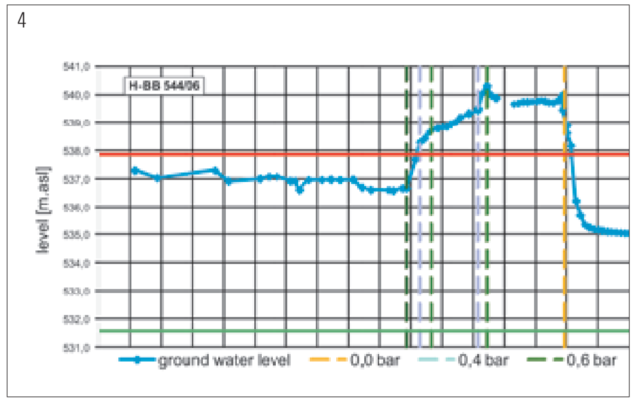

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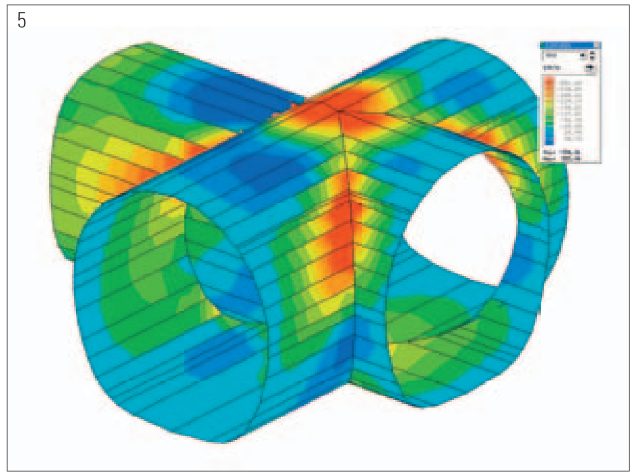

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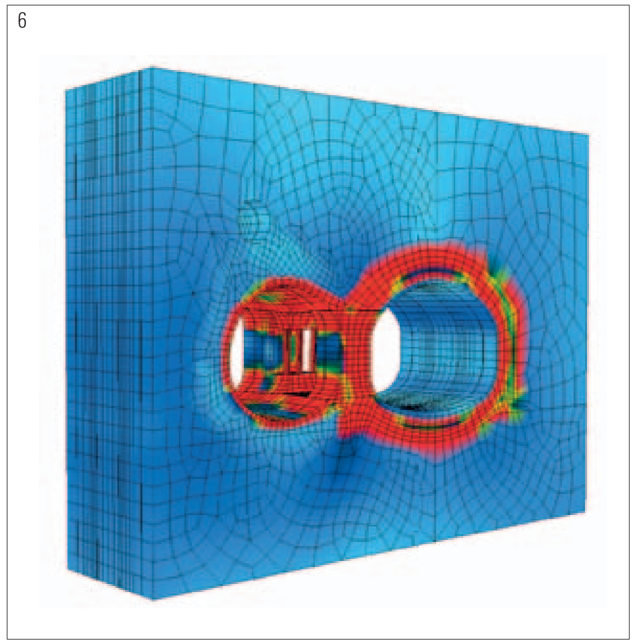
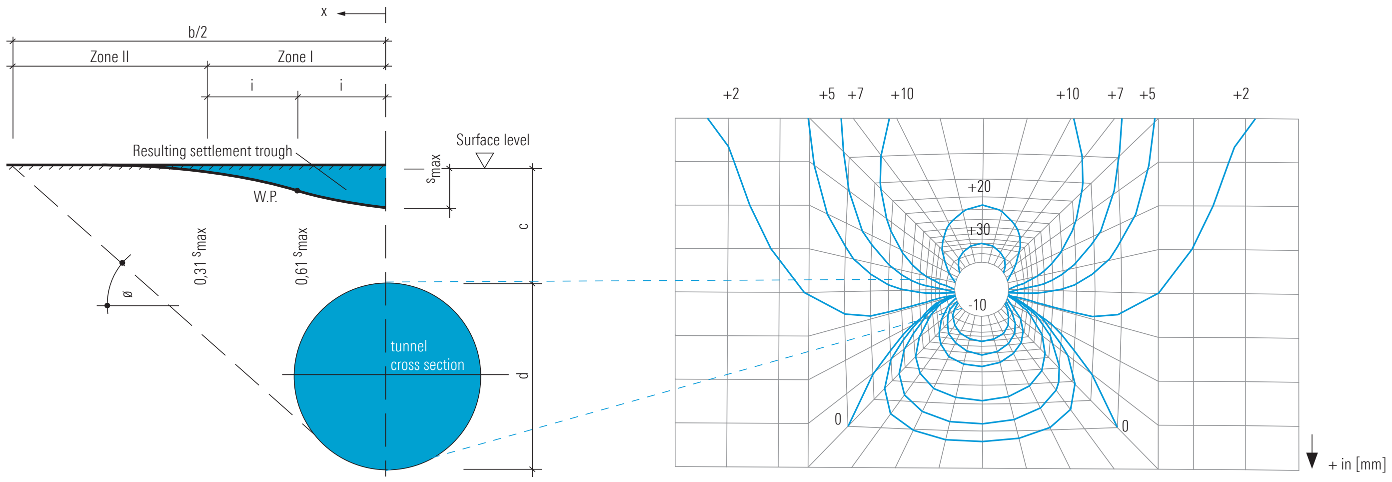
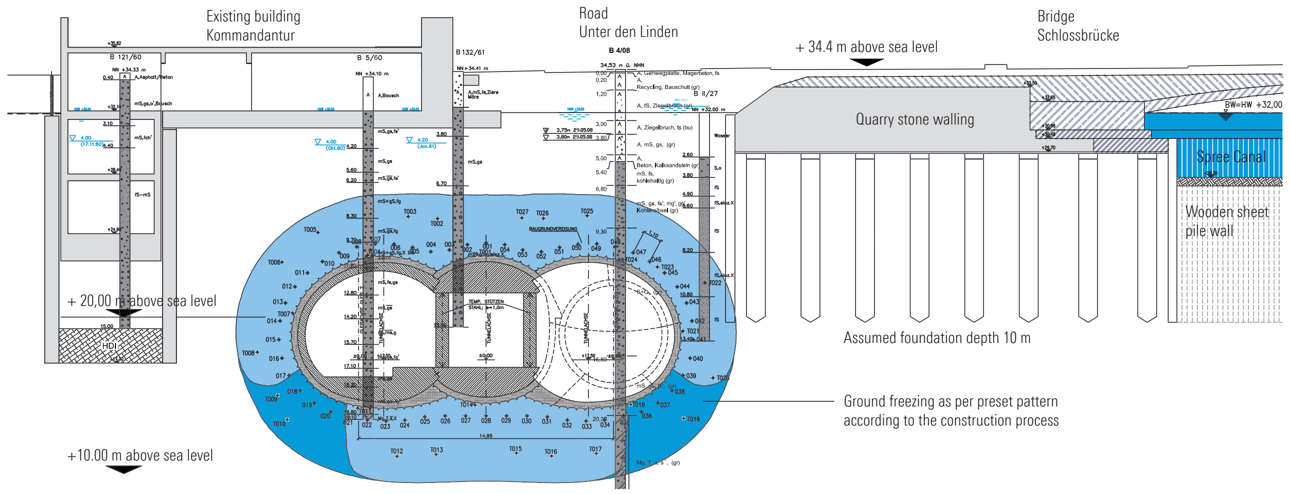


1 **Opening tubbing / entrance detail of cross cut / connecting gallery** at tubbing ring; formwork plan, Tunnel Sucharski Gdansk / Poland, outer diameter main tunnel 12.20 m
2 **Crosscut connection** – construction face Metro station Marienplatz
3 **Tunnel Offenbau** – compressed air lock
4 **Height of groundwater control level** during different pressure stages, compressed air tunnelling, below the groundwater level, tunnel lower Inn valley
5 **Finite element calculation,** opening of cross cut at tubbing ring; Finnetunnel, high speed railway line Erfurt-Leipzig / Halle, outer diameter = 10.88 m, l = 7 km, 13 separated galleries
6 **Finite element calculation,** partially longitudinal opening of shotcrete lining of existing tunnel tube in accordance of platform extension by excavating new parallel tunnel tube



Settlement calculations (volume-loss theory), surface settlements in inner-urban area lead in general to considerable damages on buildings



Ground improvement with ground freezing for underground railway line U5 Berlin, mining technique undercutting existing buildings and partially bridge „Schlossbrücke". Metro Station „Museumsinsel" is locateted under the river Spree

Identification and Evaluation of Risks for Inner-Urban Tunnelling and Countermeasures

Minimising risks – that is the motto of inner-urban tunnelling. Depending on the selected tunnelling method, there are different possibilities to limit ground deformations and thus the influence on existing infrastructure, or to keep risk as small as possible.

Settlement Calculations

Settlements are defined as ground deformations from the ground to the surface due to newly created cavities. The dimension of effects can be determined empirically and numerically by volume-loss theory or active support.

Empiric procedures as per Peck and O'Reilly/New provide a first estimation of settlement ordinates and subsidence to be expected. When the influences of the surrounding ground are to be verified in detail, two or three-dimensional finite element calculations have to be carried out.

Interactions with Buildings

Interactions between tunnelling and the ground show themselves in ground deformations, and hence in damages to buildings such as cracks, leaning etc. The variation of active support at the heading face and tunnel reveal as well as of passive support in form of adaptation of temporary lining resistance can minimise the influence of tunnelling works on buildings in consideration of the ground and water pressure. Key parameters depending on the tunnelling method are:

- support pressure
- ground conditioning
- grouting pressure
- tunnelling support
- supplementary measures
- tunnel lining
- construction process / logistics

In addition to direct influences from tunnelling, the type of foundation and its depth (bored piles, strip foundation, number of underground levels) of the undercut buildings in relation to the tunnel gradient plays a decisive role for risk assessment.
In special situations, below buildings, deformations limits, ground freezing or injections can be employed to improve the ground or underpin buildings. In special situations, below buildings, deformations can be compensated by compensation grouting.

Ground Improvement

Ground improvement is carried out to adapt the ground's characteristics to the requirements of safe construction works. Possible procedures are mechanical ground improvement by compaction or binder injection, which are again subdivided in several categories. Mechanical ground improvement is mainly used to prepare the ground and shallow footings. Methods with binder injection are applied to condition the ground in larger depth, thus providing especially for tunnel construction many advantages when done appropriately. Common methods are jet grouting or MIP (mixed in place).

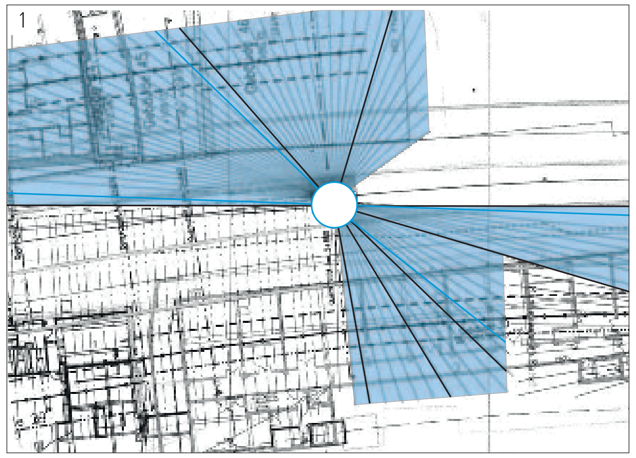
Compensation Grouting (CG)

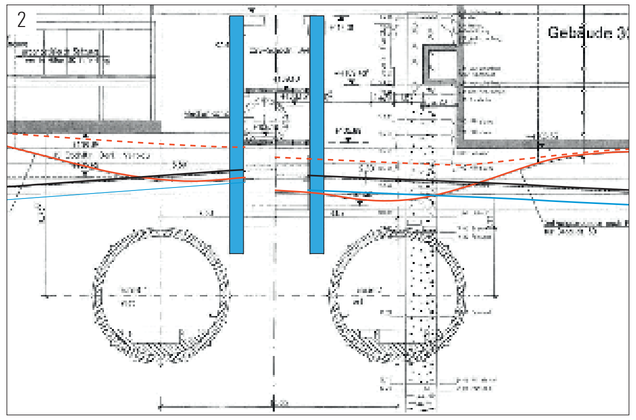
To secure particularly settlement-susceptible buildings, compensation grouting provides compensates or prevents possible vertical ground deformations by injections accompanying tunnelling works. CG consists of a first injection layer (primary fan-like injection) to stabilise the system (passive effect). The secondary fan-like injection compensates settlements by active grouting of injection material accompanying the tunnelling works. Selective (pre)lifting is also feasible.
The German Tunnel Expertise Group advises you during selection of the optimal ground improvement method to minimise settlements, as well as on the materials to be used adapted to the existing ground conditions and planned construction process. In coordination with construction works, especially the chosen tunnelling method, and with the predicted settlement development we plan the individual stages of ground injections to ensure an optimum effect of stabilising measures.

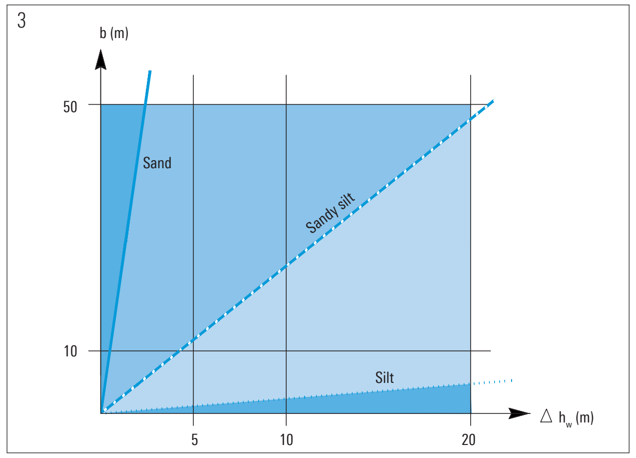
Deformation Measurements and Evaluation

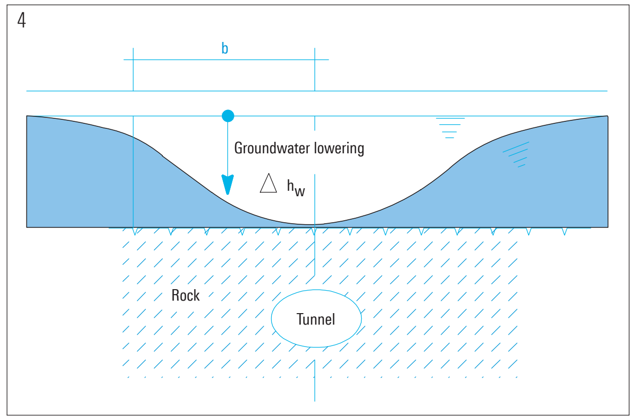
Monitoring is an essential part of tunnel construction. The metrological monitoring of tunnelling analyses the stability of the cavity by comparing measured results with calculated results. The frequency of measurements is adapted to the applied programme and tunnelling progress as well as the measured deformations.
Tunnelling in inner-urban area (with adjoining buildings and near the surface) requires in addition to convergence and ridge point measurements in the tunnel also measurements at the ground surface, in the ground and at the buildings. Settlement troughs longitudinally and transversally to the tunnel axis can present time and distance-related deformation curves and be compared to the calculated intended values.
Measurement data registered by fully automatic measurement robots but also manual measurements, still commonly used nowadays, can be analysed in real time by software and made accessible via an internet platform to everybody involved. In the framework of the measurement concept, limit values are defined and an alarm plan with intervention measures as well as a reporting chain is established.

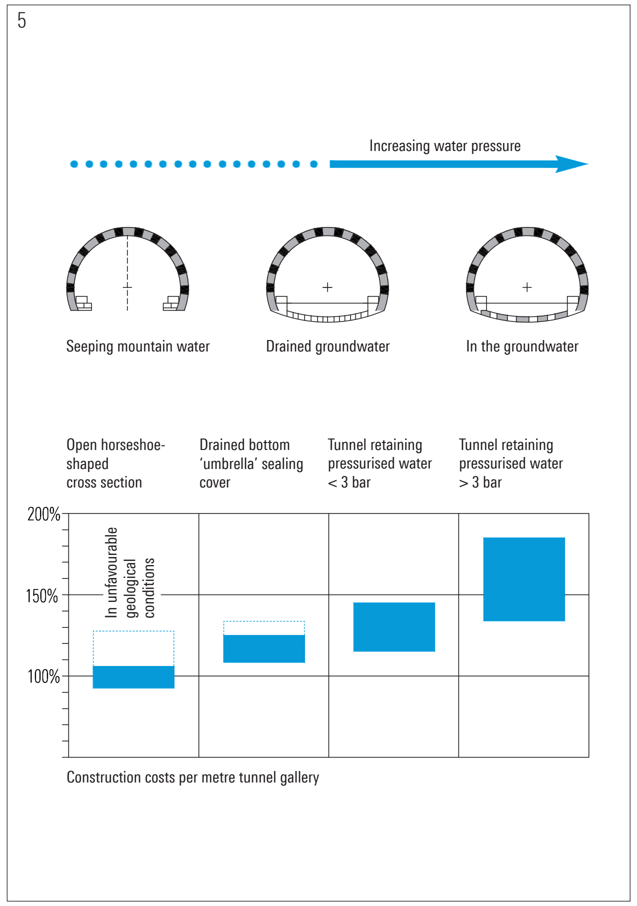
The team of the German Tunnel Expertise Group disposes of wide-ranging experience in the evaluation of ground/tunnelling interactions. Our experts provide empirical and numerical two and











1+2 Compensation grouting method under buildings, City-Tunnel Leipzig
injection area
CG shaft
— primary fan-like injection
— secondary fan-like injection
— settlement predicted
--- settlement real
1 Injected area
2 Cross section of injection shafts, tunnel tubes, buildings with deformation curves
3 Computational parameters b and h_W for the estimation of the groundwater drawdown cone
4 Groundwater drawdown cone
5 Influence of drainage and sealing concepts on construction costs

three-dimensional comparative calculations with parameter variations, which are of particular importance for inner-urban tunnel construction where buildings are undercut. Most modern software such as SOFiSTiK and AutoCAD is used. Furthermore, we support you in the evaluation and interpretation of measurement results and deliver recommendations to optimise your tunnelling project.

Vibrations

In solid and soft rock, blasting, in consideration of different boundary conditions, is often the most economic tunnelling method compared to low-vibration machine tunnelling in solid rock. Each explosion is inseparable from vibration excitation, being the most severe influence caused by this type of tunnelling. Especially in case of inner-urban tunnelling, impacts on buildings, underground pipes and conducts, soft soil (e.g. railway embankment filling) and last but not least on humans in buildings are to be examined.

In Germany, national regulations for the evaluation of short-term vibrations are stipulated in DIN 4150. In addition to vibration speed and frequency, the undercut of building structures and their use are the essential evaluation criteria. Vibration speed is influenced actively at its point of generation by excavation depth, segments, blasting pattern, explosive system, ignition stages, ignition intervals and limitation of charge quantity per ignition stage. Vibration speed is passively influenced by alternating geology, clefts, anisotropic behaviour and water saturation. This can lead to faster speeds at locations far away from the explosion than at nearer locations. Empiric formulae are available to evaluate expected vibration speeds depending on the charge quantity and the distance to the explosion. Metrological vibration monitoring of concerned buildings is indispensable. Measurement results can be made accessible online to project participants. In the framework of design, the German Tunnel Expertise Group consults you with evaluation of vibration impacts caused by blasting works. During execution together with blasting experts and in consideration of all results from vibration measurements, the necessary adaptations of tunnel blasting are specified to meet required limit values.

Drainage

Drainage is a central subject for the conception of construction and final stages as well as the design and execution of tunnel projects. The influence from groundwater and different groundwater storeys caused by tunnelling works during construction and in the final stage of the structure is to be analysed from a quantitative as well as qualitative point of view.

Drainage during Construction

During construction the spectrum of drainage, in consideration of geological, hydrological and constructional boundary conditions, goes from preceding groundwater lowering by wells to complementing measures at the tunnel (drainage drillings, sealing injections), from previous construction of drainage shafts to construction types which prevent influences on the groundwater level, or extraction of groundwater (ground freezing, compressed air tunnelling, closed shield tunnelling).
The above mentioned measures can in parts be used for shotcrete construction as well as shield tunnelling. The infiltration of groundwater, particularly during excavation works of shotcrete construction, entails significant risk potential, so that this risk factor has to be particularly taken account of.

Drainage in Final Stage

For the structure in final stage, in case of water-bearing grounds and cleft water conducts, pressure-less sealing systems with drainage at the bottom of the tunnel's side walls are analysed for economic reasons. Shallow bottoms and, depending on the geology, open bottoms are feasible. In addition to impacts on flora, fauna and buildings from the groundwater system, maintenance costs for example washing and cleaning (sinter) have to be taken into consideration. Moreover, preventive physochemical procedures can be used to keep the chalk floating, thus making it environmentally insignificant.

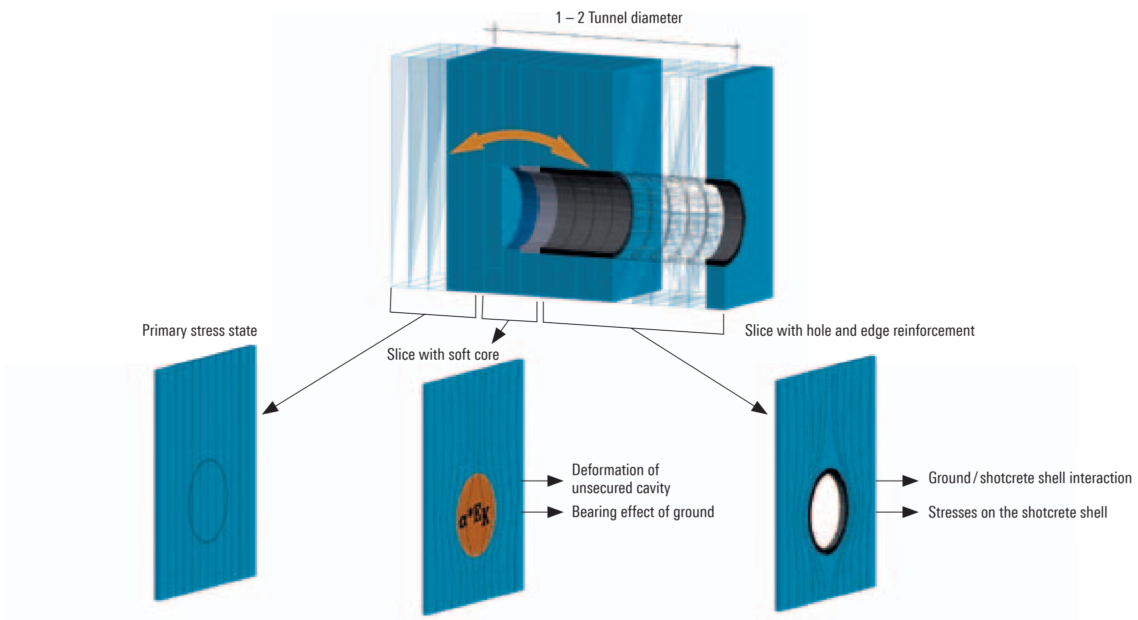
Depending on hydrostatic water pressure and concrete-damaging substances in the groundwater and on environmental regulations, water pressure tight sealing system can become necessary, implemented as all-around sealing with plastic sealing sheets and / or water-tight concrete constructions.
In case of high water pressure, for economic reasons, the concept of a pressure-regulated drainage systems has to be examined. This drainage system is used to reduce very high water pressure so as to avoid strengthening of the inner shell and structurally difficult sealing systems. With structural measures, this drainage system ensures a minimum pressure, reducing the occurring amounts of water to be diverted. The German Tunnel Expertise Group advises you during selection of the appropriate drainage system in consideration of geological and hydrogeological boundary conditions. Together with the drainage of the structure in its final stage, concepts on the basis of technical risk assessment, possible renovation efforts and expected life cycle costs are analysed. For each procedure we deliver the suitable detailed design.

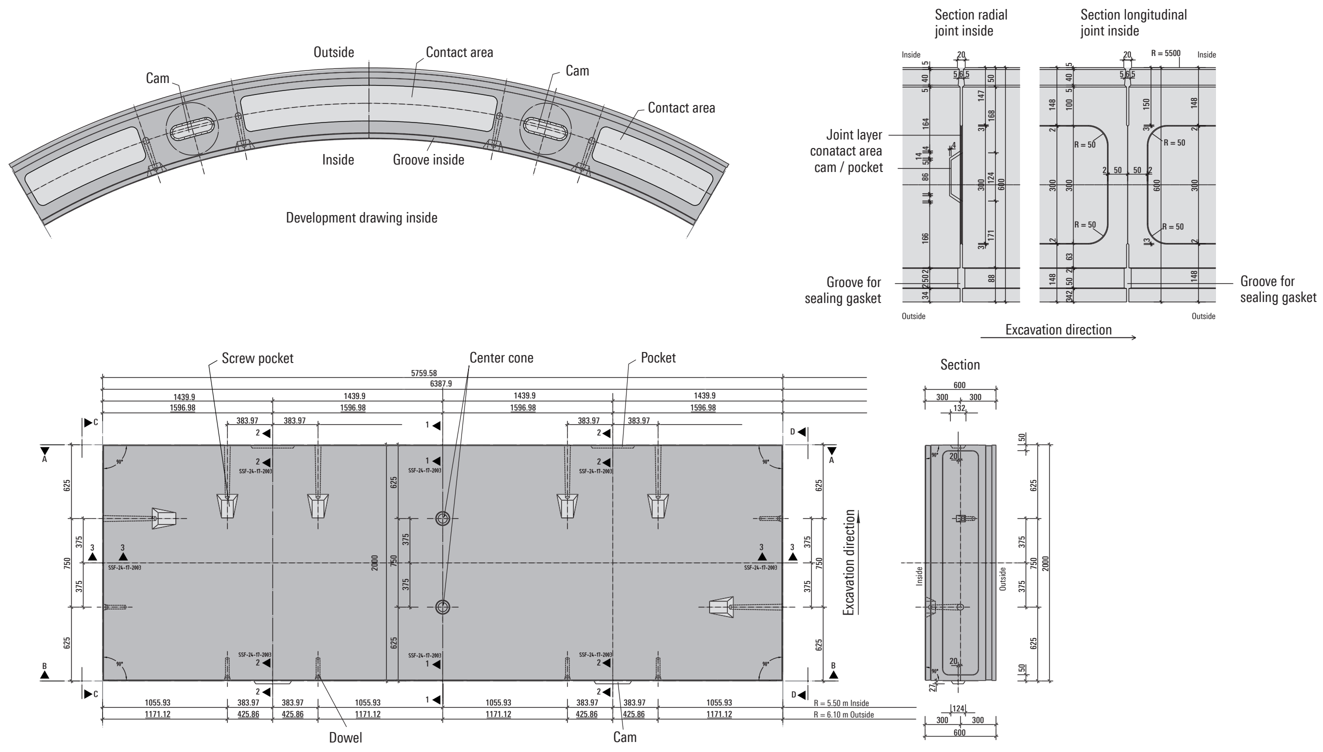
Structural analyses

Structural analyses for temporary and final tunnel lining are one of our core competences. Hydrological and geotechnical characteristics of the surrounding ground present the decisive parameters. In the structural model, by applying the existing loads, bedding characteristics can be defined and internal forces as well as deformation behaviour identified.

In consideration of arching effect and load distribution longitudinally to the tunnel, two and three-dimensional numerical models allow the following optimisations:
- minimisation of reinforcement
- optimisation of thickness of inner shell
- optimisation of tunnel lining segment design
  (ring divisions, geometry, ring joint, longitudinal joint)

Analyses of stress conditions / stress distributions, arching effect longitudinally and transversally to the tunnel axis. After excavation of the cavity secondary spatial stresses dependent on time arise. They are not caused by external influences but by primary stresses and are mainly attributable to the excavation procedure as well as the shape of the cavity.





Example of Tunnel lining segment design, Tunnel Gdansk, formwork plan

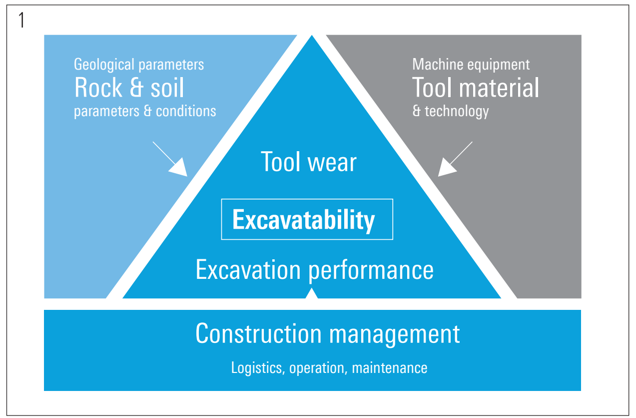
Tunnel lining segment design

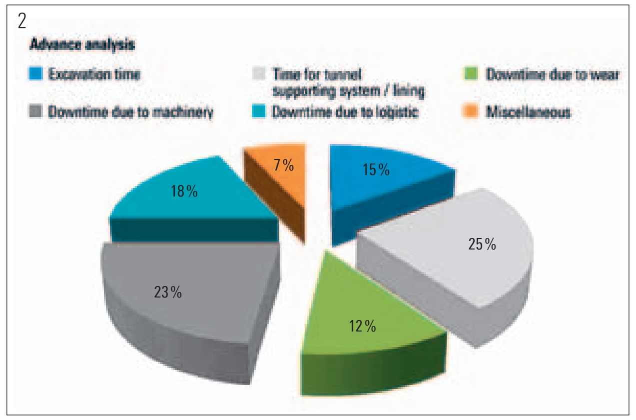
For you as client, the final securing of the cavity is the final product. A reliable design of the structure with a theoretic life cycle of at minimum 100 years is thus imperative. The German Tunnel Expertise Group follows this principle when designing and producing
- tunnel lining segment designs
- formwork drawings
- reinforcement drawings
including all detailed representations of joints, sealing grooves, screw connections, etc.

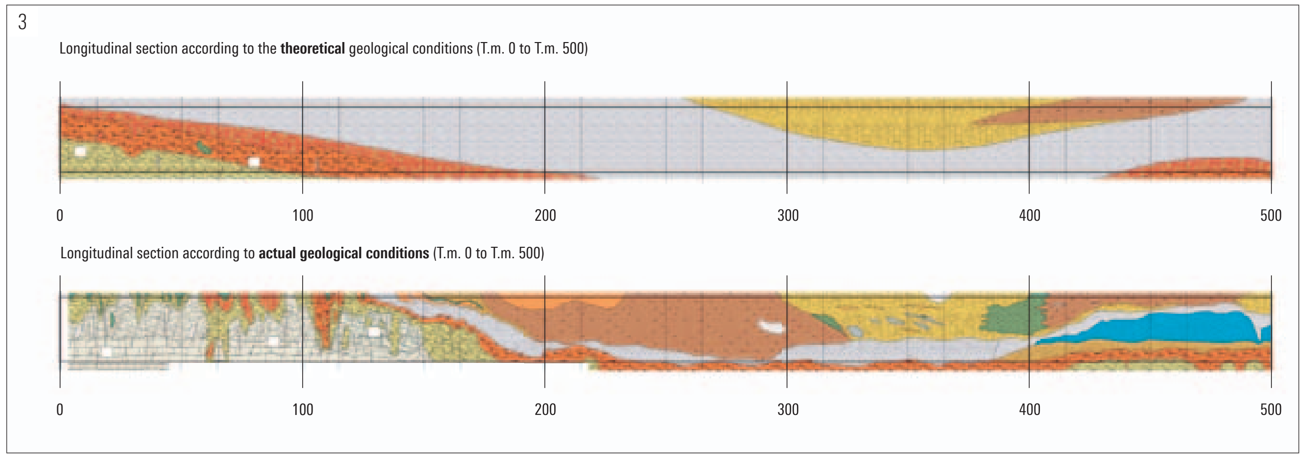
The German Tunnel Expertise Group delivers all structural analyses and design services on the basis of national and international standards and regulations. Our concepts and designs take into consideration, in close cooperation with you as our client, all current requirements of durability and serviceability, of fire protection and tightness, economic efficiency, construction logistics and best practice, including all project-specific individual parameters and boundary conditions.

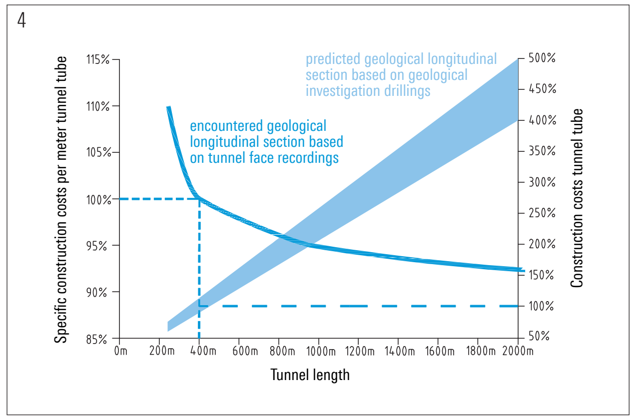
Performance and Wear Prognoses and Analyses

Performance prognoses of cyclical and continuous tunnelling methods are an essential basis of design and calculation. The prognosis of the entire performance includes the calculation of net tunnelling progress and wear as part of downtimes. For tunnelling in solid and unconsolidated rock, prognosis models are available based on rock and mountain parameters. Other parameters are the operation and operational state of construction machines / tools as well as logistical connections. Experience based on reference projects also serves to make realistic prognoses.

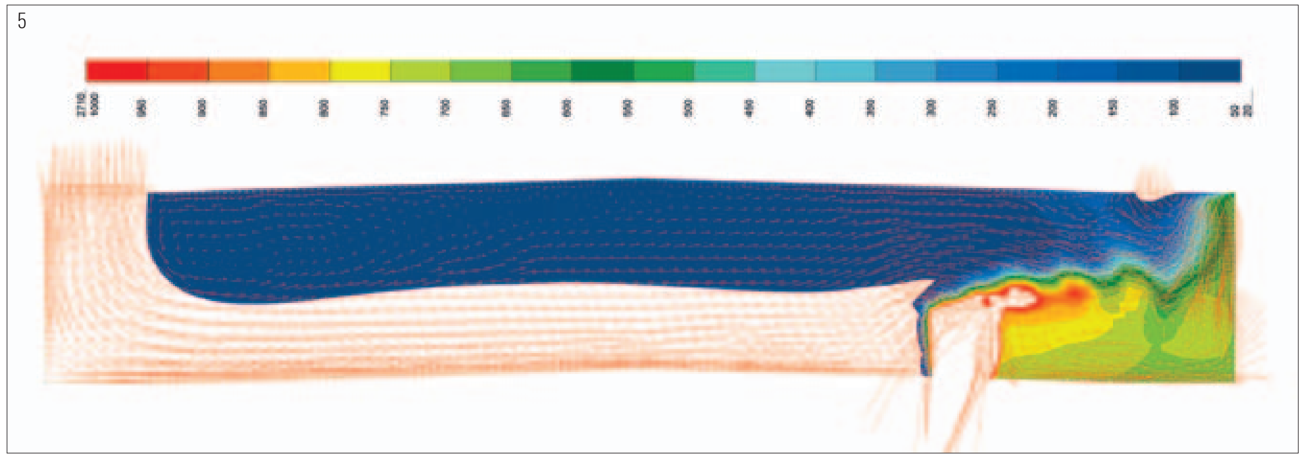








1 **Influence parameters** based on the rock/soil parameters, the tools and construction management
2 **Chart analysis** of progress and downtime,optimization by reduction of the downtimes
3 **above: predicted geological** longitudinal section based on geological investigation drillings
below: encountered geological longitudinal section based on tunnel face recordings
4 **Specific construction costs** and total costs depending on tunnel length
5 **Flow-Forming** of a tunnel fire, study for optimizing the technical tunnel equipement



In addition to performance and wear prognoses, the analysis of downtime causes, reducing the planned tunnelling progress, are of great interest. Documentation of progress, downtimes, logistics, etc. accompanying the tunnelling is hence necessary. A neutral and well-developed analysis and evaluation elaborated by the contractor and the client becomes then possible.

The German Tunnel Expertise Group supports you in the design phases of performance and wear prognoses. We deliver laboratory analyses and rock testing with standardised devices. Our knowhow in this area helps you to realistically interpret the results so that special project-specific problems are detected early during the project. Numerous reference projects, research projects and publications form a solid scientific but also practical basis. We also assist in documentation during execution and offer you a neutral evaluation basis.

Target / Actual Comparison, Claim Management

Based on the performance prognosis and analysis and tunnelling-accompanying documentation, target/actual comparison offer the possibility to put the existing ground conditions in relation to the tunnelling documentation. The integral treatment of actual and target values of ground, hydrology, tunnelling method, material parameters, tunnel support, tunnel lining etc. allows conclusions about performance losses and failure mechanisms above and underground. Causes of construction time extension and cost driving factors can be evaluated.
Target / actual comparison during tunnelling provide furthermore the possibility to adapt successively and in an optimum individual way excavation classifications.

Target / actual comparison are a neutral basis in case of alternating geological conditions, and during contractual disputes between contractor and client. The German Tunnel Expertise Group is your efficient partner in this area.

Fire protection

Fire protection is – because of recent fire incidents – one of the main focuses when constructing new tunnels and renovating old ones. The demand for a second gallery to avoid accidents and fire in the gallery of oncoming traffic is gradually implemented. Moreover, tunnels whose existing safety equipment does not correspond to regulations of the European Directive 2004 / 54 / EG are retrofitted.
Fire protection measures such as fireproof casing, sprayed plaster or admixture of polypropylene fibre to improve chipping behaviour are, in addition to a regular concrete cover of 6 cm, state-of-the-art. However, because of boundary conditions varying from one country to the other, measures are to be analysed and planned for each individual project. The most frequent fire category curves are hydrocarbon curve (HC), hydrocarbon increased curve (HCinc), Rijkswaterstaat curve (RWS), ISO834 / uniform temperature curve, ZTV-Ing curve and EBA (German railway authority) / EUREKA curve. Flow analyses demonstrate fire generation, temperature curves, speed of smoke distribution and give an overview of sight conditions in different zones within the tunnel. All relevant standards stipulate a stability verification of the tunnel in case of fire.

The experts of the German Tunnel Expertise Group simulate fire incidents three-dimensionally dynamically. Different fire loads are applied in accordance with national fire protection standards. Stability verifications in hot and cold state belong to the fundamentals of our fire protection analyses too, as well as the determination of temperature curves within the construction element 'tunnel shell'. Your result will be a final evaluation of our analyses and recommendations for the selection of the optimum fire protection system, accurately adapted to functionality, economic efficiency and the client's individual needs.

Safety (Accidents, Redundancy), Safety and Operation Equipment

Safety in the tunnel is of highest priority during its operation as well as during its construction. Without durably guaranteed safety in the tunnel by precautionary structural and fire protection measures and safety-technical surveillance and detection installations, tunnel projects cannot be approvable. An emergency concept including all possible accidents and corresponding countermeasures is thus imperative.

The German Tunnel Expertise Group supports you during compilation and evaluation of possible accidents and establishes risk analyses. With our partners form a network of current projects, we provide concepts and detailed elaborations covering the whole range of tunnel operation and safety technology.

Conclusions

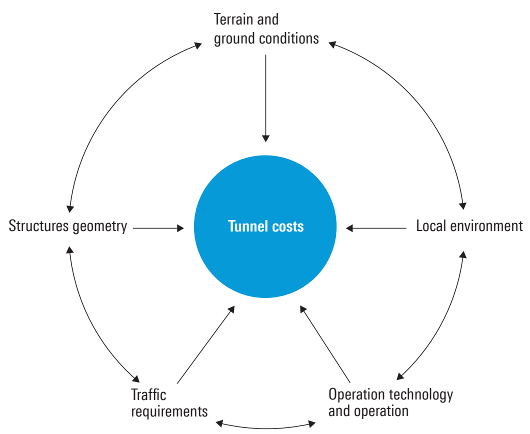
The team of the German Tunnel Expertise Group specialises in applying wide-ranging knowledge and long years of experience in the field of underground construction by intensive interdisciplinary dialogue in order to optimise projects as a whole. The assessment of execution, cost and schedule risks of complicated and difficult conditions are just as well part of our services as is the adaptation of the design to expedient and efficient practicability on site.

The comprehensive knowledge and understanding of the interaction of numerous factors when it comes to implementing underground construction sites and their interfaces enables us to optimally support you during all stages of a tunnel project.

The costs of tunnels are determined by numerous different parameters. Essential factors are of course topography and thus the related alignment (cover above tunnel, tunnel length, portal length), the defining measures of the structure (especially excavation cross section, cross-cuts, special cross sections) and the encountered ground conditions (soil, water). Local boundary conditions such as, for example, inner-urban buildings, operational equipment and traffic volume are further cost-affecting factors to be taken into consideration, and influencing each other in general. An integral approach requires thus the integration of operation, maintenance and renovation costs during the life cycle in order to calculate the total capital tie-up at the moment of first investment

Equipment, safety installations	
Lighting	Counter-beam lighting / pro-beam lighting, light control systems
Ventilation	Ventilation systems as jet fans for normal operation
Technical Traffic Installations	Basic equipment such as traffic signs and variable message signs
Central Installations	- operation rooms - power supply (UPS installation) - drainage slot gutter - control
Structural Installations	- verges - breakdown lay-bys - turning lay-bys - emergency doors - escape routes - height control - barrier systems at tunnel ends
Communication Facilities	- emergency stations - video surveillance individually controllable - tunnel radio (BOS radio) - speaker systems
Fire Protection	- manual fire alarm systems in the emergency stations - automatic fire alarm systems - manual fire extinguishers (next to emergency doors) - quenching water supply, hydrants - mechanical longitudinal venting/smoke extraction
Marking, Orientation	- escape route marking - orientation lighting - flash lights at emergency doors with video camera activation - visual guiding installations LED, regular operation - visual guiding installations LED self rescue, case of emergency

factors influencing tunnel costs



Metro U5 Berlin, from Alexanderplatz to Brandenburger Tor **l = 2 x 1.6 km, dia. = 6.40 m, cross sectional area = 32 m²**	
Client	Berliner Verkehrsbetriebe (BVG)
Planning period	2010 – 2016
Service ranges	Project planning and structural engineering: draft design, final design, tender design, geological, geotechnical and hydrological consulting for tendering and final design

Two-gallery metro line, tunnelling by shield method with fluid-supported heading face and by mining technique with ground freezing between launching pit at Rathausstrasse/track switching system up to reception point at station Brandenburger Tor. Construction of 3 metro stations: station Unter den Linden as crossing station (construction by top-down method with diaphragm walls and low injection bottom, depth up to 23 m); station Museumsinsel (station underneath Spree Canal; construction with freezing cap, station heads with diaphragm walls); station Rathaus (with sidings; construction with overlapping bored pile walls).

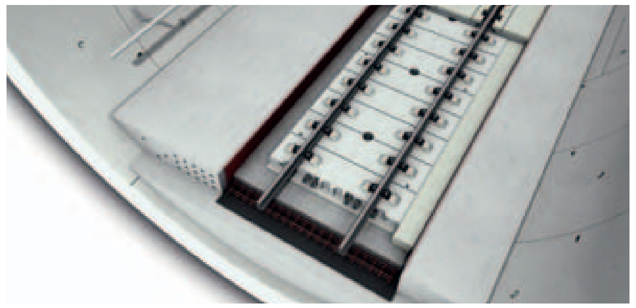
Finnetunnel, railway line Erfurt-Leipzig / Halle, shield tunnelling, **l = 6.8 km, 13 cross-cuts, cross sectional area = 18 m²**	
Client	Wayss & Freytag Ingenieurbau AG
Planning period	2008 – 2011
Service ranges	Project planning and structural engineering: approval design, final design for cross-cuts in shotcrete method, geological-geotechnical consulting

New construction of high-speed railway line Erfurt-Leipzig, tunnel boring machine, conventional cross-cut construction partially with ground freezing; tunnelling and inner shell of 13 cross-cuts in mining technique between the two main galleries with tubbings. Each 2nd cross-cut was built from two shafts to install technical equipment. At 6 cross-cuts a gate length of 12.0 m could not be realised so that 2 shafts had to be connected by an additional shaft (‚H' and ‚Z' cross-cuts).

Tunnel Katzenberg - newly built / upgraded railway line Karlsruhe – Basel **l = 2 x 9 km, dia. = 11.16 m**	
Client	Max Bögl, Bauunternehmung by order of German Railway Company
Planning period	2007 – 2010
Service ranges	Implementation planning for ballastless track design, trafficable route cover slabs, First Aid posts and light spring mass system (vibration protection)

The ballast-less track will be supplemented with a track covering system in the shafts, the portals and near rescue areas. This is the first time that a type of ballastless track is built in Germany which is passable with road vehicles. In both tunnel shafts a light mass-spring system for vibration protection is installed on a length of 500 meters.

Tunnel Katzenberg – Visualization ballastless track



Sucharski tunnel, Gdansk / Poland, road tunnel **l = 8.4 km (tunnel l = 1.2 km, dia. = 12.50 m)**	
Client	DRMG - Authority for the Development of the City of Gdansk
Planning period	2008 – 2011
Service ranges	Feasibility study, overall concept for roads, bridges and the tunnel under the Vistula River, variation study for crossing of the Vistula River as tunnel solution, project and execution planning as well as tender planning and technical instructions for implementation and acceptance of construction

The Sucharski tunnel to improve access to the port of Gdansk covers an overall length of about 8,430 m and consists of 3 working lots. The general scope of services for SSF Ingenieure in joint venture with EURO-PROJEKT Gdansk and close cooperation with Wagner Ingenieure GmbH covers the overall design together with approval planning through to execution planning. The link road is to be constructed with 2 lanes in each direction. Initially 3 lanes were intended in the tunnel as a precaution for the future. However, the 3rd lane has been waived after review of the overall investment costs and the predicted traffic development.

Metro Algiers, Extension L1B Hai el Badr - El Harrach Centre, Algeria **l = 4.0 km, cross sectional area = min. 108 m² - max. 204 m²**	
Client	EMA, Entreprise Métro d'Alger GAAMEX, Algeria
Planning period	2008 – 2010
Service ranges	Structural engineering: approval design, final design

Within the section are 4 underground stations (3 in cut-and-cover construction with bored piles and diaphragm walls, one in top-down construction with diaphragm walls) and one viaduct with approx. 300 m length, tunnel in mining and cut-and-cover technique.

Wehrhahn-Linie, Lot 1, Metro Düsseldorf, l = 3.4 km; dia. = 9.5 m	
Client	City of Düsseldorf, Authority for traffic management
Planning period	2008 – 2011
Service ranges	Structural engineering: approval design, final design Ramp Bilk (South): approx. 175 m Ramp Wehrhahn (East): approx. 250 m Starting pit Königsallee (centre): approx. 50 m

Final design of the ramps to both ends of the 3.4 km long subterranean inner-urban underground line incl. starting and reception pit for TBM and of the additional starting pit at Königsallee. Construction of ramps in open diaphragm wall pit, partially in top-down construction method.

Gdansk inner port, shipyard looking downstream to the future tunnel crossing

Metro Delhi, station Malviya Nagar, station Hauz Khas, India
l = 3.8 km, dia. = 2 x 5.8 m

Client	Delhi Metro Rail Cooperation MTG, Metro Tunneling Group
Planning period	2007 – 2010
Service ranges	Preliminary design of the stations and the track approval design, final design of the stations

Station Malviya Nagar is constructed with pit lining made of soldier pile walls and rock nailing; station Hauz Khas is built in top-down method with diaphragm walls. The starting pits for the tunnel boring machine are produced in cut-and-cover technique. Each of the stations has a length of 318 m and is 20.65 m wide.

City-Tunnel Leipzig with 4 stations
l = 2 x 1.4 km, dia. = 9.0 m

Client	Free State of Saxony, City of Leipzig; DEGES Deutsche Einheit Fernstraßenplanungs- und -bau GmbH
Planning period	2006 – 2010
Service ranges	Calculation of ground/structure interaction in the area of several buildings, client consulting, implementation design for TBM accesses

Erection of the 2-track electrified line from station Bayerischer Bahnhof to Central station. The tunnels are constructed by shield tunnelling with hydro-shield; the diameter of both single-tracked shafts is 9.0 m. During construction, 4 subterranean stations are erected; the access to the tunnel is assured by 3 ramps in cut-and-cover construction. During shield-tunnelling several, partially low covered buildings are underpinned. To secure buildings and to limit settlements, comprehensive measures for stabilizing and lifting of the ground are put into use.

Metro Amsterdam, North/South Linie, station Vijzelgracht, Netherlands
l = 1.3 km, dia. = 9.0 m

Client	City of Amsterdam, Infrastructuur Verkeer en Vervoer, Max Bögl Noord/Zuidlijn Amsterdam v.o.f.
Planning period	2003 – 2010
Service ranges	Approval design, workshop drawings, final design

The station Vijzelgracht is one of in total 8 stations on the 9.5 km long north-south Top-down construction method under compressed air; diaphragm walls with glass fibre reinforcement; utility surface of the station: 60.000 m². Diaphragm walls 1200 to 1500 mm thick; depth between 36 and 45 m; 20.000 m² HDI; 200.000 m³ concrete; 26.000 t BST. line.

U3 Nuremberg north-west, stations Friedrich-Ebert-Platz + Kaulbachplatz
l = 661 m, cross sectional area = up to 109 m²

Client	Joint Venture Underground Nuremberg, U3 North west, BA AG3 c/o HOCHTIEF Construction AG
Planning period	2007 – 2010
Service ranges	Project planning and structural engineering: approval design, final design station Kaulbachplatz: pit securing, makeshift bridge; station Friedrich-Ebert-Platz: pit securing, makeshift bridge, noise protection, structure with staircases; reception pit: pit securing, structure with emergency exits; tunnel line: tunnelling, inner shell; mass-spring elements for the whole structure. Securing of tunnelling works, structure and track slab

Expansion of underground line U3 in limited inner-urban traffic spaces. Construction of station Kaulbachplatz in cut-and-cover method with separated bored pile enclosures. Makeshift bridges with variable openings to maintain individual traffic. Implementation of the alternative proposal 'top-down construction' at station Friedrich-Ebert-Platz to quickly re-establish tramway and main road traffic. Complete final design for pit enclosures and track slabs. Line structures 1 and 2-tracked with widening areas in mining technique. Reception pit with temporary end point of tunnel line.

Barbarossa Tunnel + Löwenherz Tunnel, Nordhausen
l = 179 m / 193.5 m, cross sectional area = 14.5 – 27.9 m²

Client	Schachtbau Nordhausen GmbH
Planning period	2010
Service ranges	Project planning and structural engineering: approval design, final design; emergency gallery and escape ways (structural analysis, tunnelling, lining, rein-forcement, drainage, road construction drawings); pit securing for portal cutting

Retrofitting of escape ways of the existing road tunnel of B10 town bypass Annweiler at Trifels. Two emergency galleries by mining technique as well as 5 escape ways in the area of the gallery structure. Mined galleries with double-shell shotcrete vault and cast in-situ bottom slab, mined opening area l = 12.5 m for power supply unit. Tunnelling in clefty sandstone with covering heights of around 35 m. Ventilator unit in cut-and-cover construction method with angular retaining walls.

Metro U15 Stuttgart-Zuffenhausen
l = 581 m, cross sectional area = 67 m²

Client	Ed. Züblin AG
Planning period	2008 – 2009
Service ranges	Project planning and structural engineering: approval design final design - for ‚closed' construction with emergency exits and cross-cut - for tunnelling and reinforcement of inner shell

Double-tracked tunnel structure part of the expansion of the underground line U15 Stuttgart-Zuffenhausen with settlement-sensitive buildings nearby and a railway undercrossing. Inner shell made of underwater concrete. Cut-and-cover and ‚closed' construction. Closed construction by excavator and blasting to loosen the ground.

Jin Shazhou-Tunnel, China
l = 4.5 km, cross sectional area = 100 m²

Client	PEC + S Planning, Engineering, Consulting + Services GmbH, China
Planning period	2006 – 2009
Service ranges	Construction supervision; consulting in view of implementing internationally applied quality and safety standards; short expert reports

Tunnelling was carried out in conventional construction method with partially only 6 m covering in water-sensitive, unconsolidated rock and in karstified mountain area. Populated area and important motorway connections have been undercut. An additional measure consisted of using pipe roofing and injection pipes as well as calotte bottoms. A 1-km-long section was built by open construction techniques (cut-and-cover or trough method).

Tunnel at Tegel Airport Berlin (motorway A111)
l = 1.5 km (900 m + 620 m), cross sectional area = 125 m²

Client	DB ProjektBau GmbH Regional office East
Planning period	2007 – 2008
Service ranges	Design of general renovation, technical and safety retrofit

For general renovation and security retrofit, both tunnel shafts were shut down completely at the same time. The decisive reason for that was next to the qualitatively high implementation, the efficient and interface-reduced execution of the works in order to completely remove the whole tunnel core and renew the traffic, operation and especially safety relevant technology installations.

Metro Munich-Moosach, line 3 north, crossing station Moosach
l = 340 m, cross sectional area = 125 m²

Client	ARGE U3/3 Moosach, Max Bögl Bauunternehmung GmbH & Co. KG/Swietelsky Baugesellschaft mbH
Planning period	2006 – 2009
Service ranges	Structural engineering: approval design, final design for sidings (top-down construction with diaphragm walls) and park and ride area

Construction of an underground station with sidings and park and ride area in the crossing area of the regional train Munich. Inner-urban construction including different construction phases due to traffic management. Diaphragm wall (t = 120 cm, max. length approx. 30 m), top-down construction. Partial arrangement of large bored piles DN = 150 (approx. 30 m pile length) with 12° inclination to secure adjacent buildings. Five crossing culverts, partly pipe jacking. Structure lies completely underneath the groundwater level (around 20 m centimetres of water).

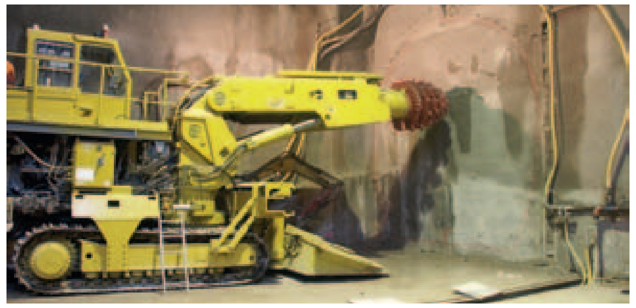
Traffic link of the Berlin-Brandenburg-International Airport. Tunnel and trough line of regional train and long distance train, double-tracked, lines 6008 and 6151; l = Tunnel 243.1 m / Trough 2.467 m; dia.= Tunnel 10.60 m / Trough 10.60 + 21.60 m

Client	German Railway Company, DB ProjektBau GmbH Regional office East, Large scale projects north-south axis,
Planning period	2007 – 2008
Service ranges	Project planning: final design; structural engineering: approval design, final design

Line in tunnel and trough, divided in 8 sections with trough and full frame construction method for double-tracked long distance train and regional train line – connection of Berlin-Brandenburg-International Airport. Partial widening to 4-tracks in the area of the trough. Several crossing structures nearby over the tunnel and trough. Construction of trough and tunnel structure with sheet-pile walls and underwater concrete bottom; partially back anchored with GEWI piles as anti-floating securing.

Metro Station Vijzelgracht, Amsterdam – construction phase/employment of machinery under the intermedite ceiling

Metro Station Kaulbachplatz, Nuremberg – construction phase/mortiser



Tunnel at Tegel Airport Berlin (motorway A111) – final state

Metro Station Moosach, Munich – construction phase

Metro North-South-line, Cologne, 1. and 2. Construction stages
l = Tunnel 600 m / Ramps 900 m, cross sectional area = 63,5 m²

Client	IBS-Köln / PSP Beratende Ingenieure, Munich Cologne transport association, KVB
Planning period	2006 – 2008
Service ranges	General planning: basic evaluation, preliminary design, draft design, approval design, final design, implementation design, preparation and evaluation of tenders for double-tracked tramway.

Tunnel and ramp construction in groundwater protecting construction method (open diaphragm wall technique with underwater concrete) within urban area 600 m long. Tramway traffic installations double-tracked, 900 m long. Ancillary measures for German railway company (retaining walls, railway bridges), road traffic installations; conduits and supply installations. Diaphragm walls (t = 0.80 m) up to 19 m deep. Underwater concrete bottom up to 13 m under top edge of groundwater.

Metro shuttle U55 Berlin Lehrter Bhf. to Brandenburger Tor
l = 90 m, cross sectional area = 200 m²

Client	Joint Venture U55, station Brandenburger Tor c / o HOCHTIEF Construction AG
Planning period	2004 – 2007
Service ranges	Structural engineering: approval design, final design

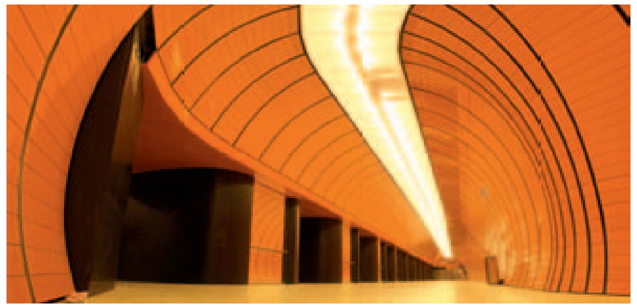
Continuation of the underground from the finished shield tunnelling section at BrandenburgerTor / Hotel Adlon.
Exit structures in cut-and-cover method; construction of the 3-part cross section of the platform area in 'closed' construction method during several stages with combined bearing system made of partial inner shell and outer shell; tunnelling of galleries partially in the groundwater and unconsolidated soil with shotcrete method under a freezing cap. Structure length of 'closed' construction = 90 m.

Maglev train Munich Central Station – Airport, Section 3, Airport Tunnel
l = 884 m, dia. = 8.0 m

Client	German Railway Company DB Magnetbahn GmbH, Munich
Planning period	2003 – 2007
Service ranges	Preliminary design, approval design

Tunnel drive with shield machine, the entry to the maglev station Airport is assured by two single-tracked tunnel shafts underneath the tarmacs west with connecting shaft and emergency exit in the middle of the tarmacs. The starting pit that will be transformed to a groundwater trough or a covered tunnel with 450 m length after tunnel driving is situated near the western connection. This pit is built in cut-and-cover method with ground securing by underwater concrete and injection piles.

Metro Station Marienplatz, Munich – tunnelling method by using soil freezing



Metro station Marienplatz, platform widening
l = 98 m / 103 m, cross sectional area = 55 m²

Client	City of Munich
Planning period	2003 – 2006
Service ranges	Structural engineering: approval design, final design

Shotcrete construction method with ridge securing under freezing cap; tunnel breakout under freezing shield; the connection of the two new pedestrian tunnels to the station Marienplatz necessitate underpinning and breakouts of the existing diaphragm walls and outer walls of the structures with roof and ground underpinning. Bavarian State Price for the plan design.

Dortmund, line III east, construction section 2 Ostentor
l = 1.3 km, cross sectional area = up to 178 m²

Client	Wayss & Freytag Ingenieurbau AG
Planning period	2002 – 2005
Service ranges	Structural engineering: approval design, final design for tunnelling and pit securing, makeshift bridges and final structures.

Inner-urban tunnel in the centre of Dortmund, built by simultaneously maintaining main through traffic and tramway transport also in the area of intersection Schwanenwall / Hamburger Strasse. Subterranean construction of three-part tunnel cross section with up to four tracks and an undercrossing double-tracked branch-off. 'Closed' construction in double-shell method with temporary ridge securing.Cut-and-cover construction with frame and trough structures.

Motorway ring A99 Munich, Tunnel Aubing
l = 1.9 km, ramps l = 530 m, cross sectional area = 135 m²

Client	Authority of motorways, South Bavaria
Planning period	2000 – 2004
Service ranges	Preliminary design, workshop drawings, preparation of tenders

Tunnel Aubing as part of the 6.2 km long west section of motorway A99. Construction in cut-and-cover method; divided in several sections: ramp north as groundwater trough / northern tunnel with undercrossing of the railway line Munich – Augsburg, tunnel above ground, undercrossing of railway line Munich – Lindau, ramp south as groundwater trough; tunnel length including ramps 2.425 km with a motorway cross-section of 2 x 13.50 m clearance (2 tracks / 4 lanes). Groundwater trough up to 7.50 m deep. Measure includes design of operational buildings with pump installations; underpinning of railway bridge over the tunnel.

Tunnel Aubing, Munich ringroad A99 west section – Tunnel portal south

Tunnel Offenbau, high speed railway, Nuremberg – Ingolstadt, Lot North
l = 1.3 km, cross sectional area = 100 m²

Client	German Railway Company DB ProjektBau GmbH, Branch South, Project Center Nuremberg
Planning period	2001 – 2003
Service ranges	Structural engineering: approval design, final design

Top-down construction under compressed air in settlement susceptible ground and artesian pressurized groundwater; superimposed bored pile walls, concrete cover; construction of inverted arc with shotcrete method under compressed air representing an innovation for this construction technique. The shotcrete is injected under compressed air. After production of the inverted arc the compressed air is turned off and works on the inside can be done completely atmospheric.

Road tunnel Bramschstraße, Dresden: l = 480 m; l = 1.3 km, cross sectional area = 100 m²

Client	Max Bögl Bauunternehmung GmbH & Co. KG
Planning period	1999 – 2002
Service ranges	Project planning and structural engineering: complete final design of structures, tunnelling and pit securing measures

New construction of north tangent Gorbitz with open and closed construction methods. Construction of trough sections and partial areas of the tunnel in cut-and-cover method. The tunnel areas built by mining technique were blasted at 5 to 12 m underneath the foundations of existing buildings. Single- and double-cell cross section in cut-and-cover method and with groundwater troughs. Pit securing with separated bored pile walls. Almost circular, water pressure-retaining cross section in double-shell closed construction method.

Tunnel Göggelsbuch, high speed railway, Nuremberg – Ingolstadt, Lot North
l = 2.3 km, cross sectional area = 150 m²

Client	German Railway Company, DB ProjektBau GmbH, Branch South, Project Center Nuremberg
Planning period	1998 – 2002
Service ranges	Master planning for the final design

Tunnel in mining technique (shotcrete in unconsolidated material; double layer sheeting). Construction of portals in cut-and-cover method (nail walls with shotcrete). Construction of tunnel in partial breakouts (continuous calotte, bench, bottom). Securing of breakouts and temporary sheeting: reinforced shotcrete, anchor bolts and arcs. Minimum thickness of tunnel inner sheeting 35 cm; length of sections: 12.50 m. Emergency exit in the middle of the tunnel consisting of a 30 m deep shaft and longitudinal and transversal pits.

Tunnel Göggelsbuch – vault formwork traveller

More reference projects

Project planning and structural engineering in Germany

Road tunnel Petuelring / Schenkendorfstraße, Munich | Metro Fürth, station Hardhöhe with line section and shunting yard | Metro Nuremberg, U3 south-west, station Gustav-Adolf-Straße | Metro Nuremberg, U3 south-west, station Sündersbühl | Metro Fürth, U1, station Klinikum with line section | Metro Düsseldorf, Wehrhahn line, lot 1, stations Jan-Wellem-Platz, Pempelforter Straße | Tunnel Kreuzstraße in Tuttlingen | Tunnel Schleifenstraße, Augsburg | Metro station Wettersteinplatz, Line 1 south, lot 2, Munich | Loreley and Rossstein Tunnels | Renewal of the old tunnels in the City of Mainz, upgrade of railway line 31 Mainz to Mannheim | Tunnel Leutenbach | Tunnel Gevelsberg | Metro Cologne, North – South-Line 2nd construction stage

Geological, geotechnical and hydrological consulting

with attrition prognoses, water drainage, geological reports, recommendations for machine and conventional tunnelling, cartography, geological documentation, consulting on contract addendums, geotechnical construction management.

Germany

Railway tunnel Himmelberg, high-speed railway line | Railway tunnel Schulwand, high-speed railway line | Railway tunnel Wahnscheid, high-speed railway line | Metro Dortmund, line III east | Railway tunnel Geisberg, cut-and-cover method | Renewal of the old tunnels in the City of Mainz, upgrade of railway line 31 Mainz to Mannheim | Railway tunnel Audi north | Canal conversion Munich ring road east | Metro Munich line 6 north, lot 7, Garching | Tina gallery, Aßling | Tunnel Augustaberg | Tunnel Siegkreisel Betzdorf | Metro Cologne, North –South-Line 1st construction stage | Metro Cologne, North –South-Line 2nd construction stage | Metro Cologne, North –South-Line shield tunnelling north | Ring road Erding, gap closing, package B, lot 2, Munich | Road tunnel Eisgrub, B15 Regensburg – Landshut – Rosenheim | Metro Munich line 3 north, lot 1

Austria

Stubnerkogel Tunnel | Investigation gallery Fiecht Tunnel | Birgl Tunnel | Railway tunnel H5 Vomp – Terfens, H5V lot extension, H6 gallery Terfens, Lower Inn Valley | Railway tunnel Brenner Base Tunnel | Railway tunnel Münster Wiesing | Tunnel Arlberg, lining works | Tunnel Kenlach and tunnel Birgl, Tauernachse Brandstatt – Loifarn, Schwarzach/St. Veit

International

Middle Marsyangdi hydro-electric project, Nepal | Railway tunnel, high-speed railway line Hefei-Nanjing, China | Railway tunnel, high-speed railway line Jing-Jin, China | New Railway-Line Kalambaka – Kozani, Lot Dimitra – Siatista, Greece

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