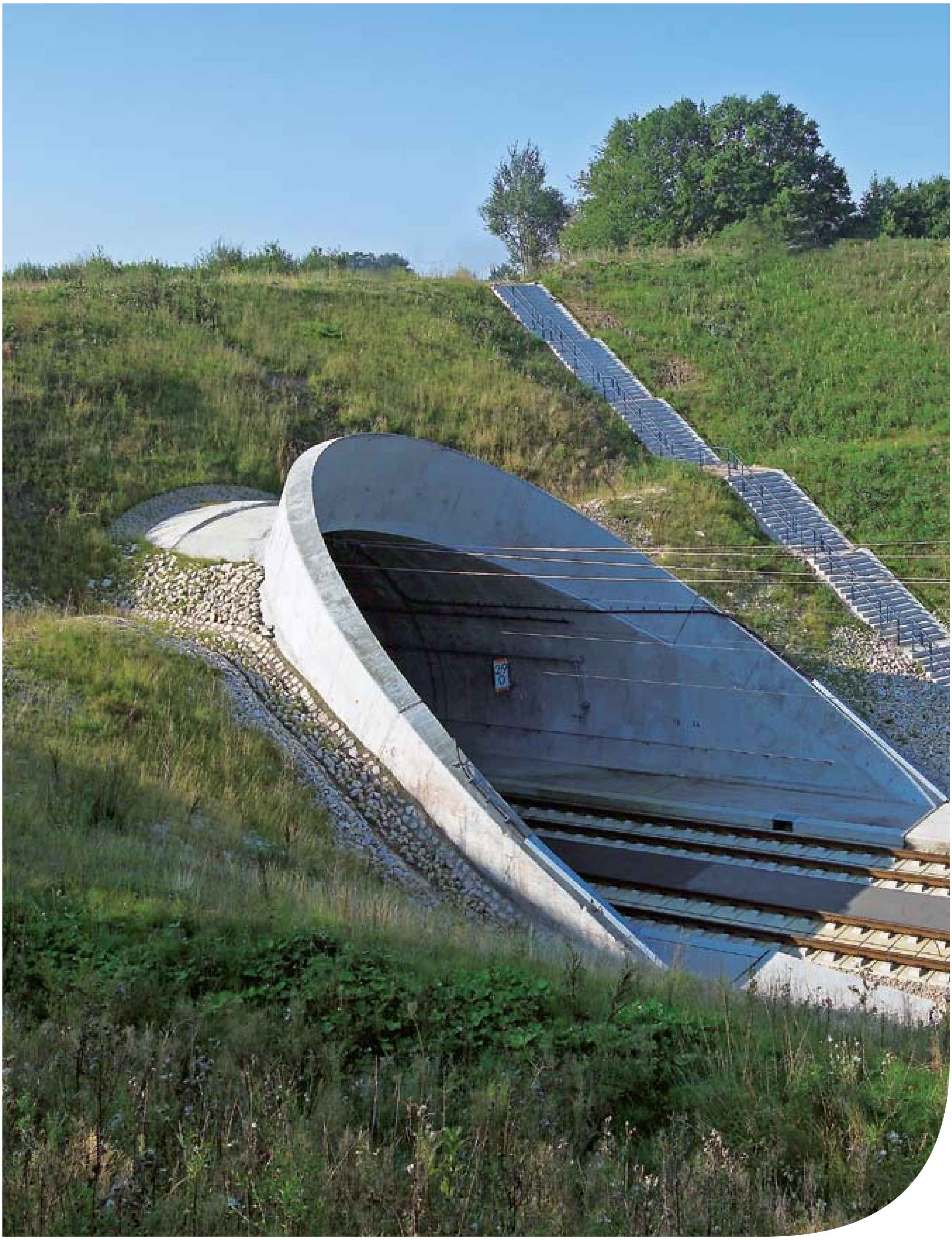
Tunnels on the newly built line Nuremberg–Ingolstadt

Lot North – Tunnel Göggelsbuch / Tunnel Offenbau

SSF Ingenieure



Picture credits: Photographie Wolfgang

In order to manage requirements of intensified passenger and freight railway traffic after the German reunification and the enlargement of the European Union to the East, comprehensive infrastructure measures are necessary which improve and replenish the existing railway network. Moreover, the advancing European integration necessitates the creation and expansion of a trans-European traffic network. The high-speed railway line from Nuremberg to Ingolstadt and Munich is situated in this context. This line section is the extension of the traffic project "German unit n° 8" reaching from Berlin to Nuremberg passing Halle/ Leipzig and Erfurt. It lies also within the axis n° 1 (Berlin – Verona – Palermo) of the Trans-European Transport Network.

The line is divided into the newly built section between Nuremberg and Ingolstadt and an upgraded part between Ingolstadt and Munich. The alignment was chosen in such way that mixed traffic of passenger and freight transport is possible. The maximum longitudinal inclination of 20 per mill, a minimum curve of 22,500 m and a minimum radius of 3,700 m allow freight traffic to run at 160 km/h at night. The design speed for passenger traffic is 300 km/h. The superstructure is built on the entire line as ballastless track. The total length of the newly built line is approx. 83.3 km. The line was divided into five construction lots.

The 35.02 km long newly built section runs in large parts parallel to the motorway A9 in order to avoid another cut across the landscape. Especially the predetermined alignment aiming at a traffic routes bundling entailed 22 road bridges and culverts, 32 railway bridges, slope securing measures, a 3.5 km long elevated track section on deep foundation as well as the two tunnels at Offenbau and Göggelsbuch. In total, 2.60 million m^3 of earth were moved for lot north only.

New line Nuremberg – Ingolstadt, lot north – bridge over the Main-Danube-Canal

SSF Ingenieure was charged by the construction consortium with general planning of the final design, with the main emphasis on:

- Foundations and soil mechanics
- Railway line design with ballast-less track
- Road planning in view of accompanying and crossing routes
- Railway bridges (Schwarzachtal, Main-Danube-Canal)
- Road bridges (fly-over motorway A73, fly-over junction Hiltpoltstein, road bridges St2225 and St2227)
- Design tunnel and trough constructions (Offenbau, Göggelsbuch)
- Stations and belonging installations (regional station Allersberg)
- Slope securing measures (Auer Berg)
- Design of elevated track
- Noise barriers
- Landscape protection measures
- Administrative procedures and agreements on maintenance in railroad right-of-way
- Coordination with technical equippers
- Plan modification procedures

Tunnel Göggelsbuch – main shaft in direction north

Tunnel at Göggelsbuch

The tunnel Göggelsbuch, part of lot north of the new ICE railway line Nuremberg – Ingolstadt, underpasses on 2.3 kilometres a small hill near the town of Göggelsbuch as well as a parking area with toilet facilities at motorway A9. Starting from both portals, the tunnel was drilled by mining technique. Completion was in 2002.

With a covering of 5 to 22 m the tunnel Göggelsbuch is situated completely in rock material of the Feuerletten Formation of Middle Triassic origin and thus entirely in unconsolidated rock material. For reason of the water pressure occurring at 3 bar, the tunnel was built with an excavation cross-section of around 150 m^2, formed completely as inverted arch. Heading of the 2,223 m long mined tunnel started from the north and the south portal at the same time. First of all, the calotte was driven with a continuous calotte bottom; next, bench and tunnel floor were constructed. The encountered rock material was removed by an excavator in all partial cross-sections. As habitual for the NATM, arches, shortcrete, anchors and pikes were utilised for securing. The distance between pulls was at maximum 1.30 m. The fossil separating layers within the Feuerletten Formation had to be secured during drilling by preceding pikes and at the heading front by shotcrete.

After excavation, interior lining was executed from the south end with a 3 mm thick all around sealing that is resistant against water pressure as well as with a 35 cm thick reinforced inner shell

Tunnel Göggelsbuch – emergency exit direction rescue shaft

whose production was divided into bottom and vault construction. One block is 12.5 m long. With regards to the limited construction time a 70 m long tandem formwork traveller was especially constructed for building the tunnel bottom so that two bottom sections could be concreted per day. The portal areas connected to the surrounding road network were built in top-down method and are in total 65 meters long.

For safety reasons concerning fire prevention and catastrophe relief, rescue areas were arranged at both portals and an emergency exit was built in the middle of the tunnel in form of a 30 m deep shaft that can be accessed through two 150 m long escape shafts running parallel to the tunnel. The escape shafts are separated from the main tunnel by lock doors. The breakthroughs cross-section reaches 18 m^2. The shafts were built by means of a roadheader. Securing measures during drilling were the same as used for the main tunnel boring.

Tunnel Göggelsbuch	
Tunnel length	2.287 m, 2.223 m by mining technique
Masses	350,000 m³ excavation, 50,000 m³ shotcrete 25,000 anchors, 23,000 pikes, 90,000 m² sealing, 60,000 m³ reinforced concrete, 5,000 t reinforcing steel
Construction period	Inner layer 12 month, Total construction time structure shell 26 month
Client	DB AG (Germany railway company), represented by DB Projekt Bau GmbH PZ, Nuremberg
SSF Ingenieure	entire final design

1 Tunnel Göggelsbuch – vault formwork traveller
2 Tunnel Göggelsbuch – concreting
3 Tunnel Göggelsbuch – air arc construction
4 Tunnel Göggelsbuch – south portal during construction

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Picture credits: ARGE NBS Nürnberg - Ingolstadt Los Nord

Tunnel at Offenbau

The town of Offenbau in the bourough of Thalmassing is situated directly next to the federal motorway A9 and the newly constructed high-speed railway line Nuremberg – Ingolstadt. To diminish the impact on the residents next to the railway line, a complete covering of the new line off the town was stipulated during plan approval. Furthermore, it was required to only lower the groundwater restrictedly during construction.

The initial concept planned to construct the tunnel with footings as rectangular cross-section in cut-and-cover method within sloped, back-anchored excavation pits. In the offer to the functional tender of the new construction of the line from Nuremberg to Ingolstadt, already a cost-optimized specific proposal of a statically optimized vault formation had been developed and finally chosen. But shortly before tunnelling works started, the already concreted base slabs in the southern section lifted and the slopes started sliding. Construction works were stopped in order to search for the causes.

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It was then discovered that settlement susceptible ground as well as artesian confined groundwater underneath the Quaternary non confined groundwater horizon made the implementation of the initial design impossible.

Securing against base heave of the ground, securing of the slope as well as the non-predictable ground characteristics of the weathered Opalinus clay relevant to the envisaged cut-and-cover method entailed a revision of the initial concept presenting special endeavours:

- Safety against base heave of the ground under cut-and-cover construction method without groundwater drainage in Opalinus clay was not given
- Securing of the slope was not feasible under cut-and-cover construction without groundwater drainage because of possibly occurring slope breaks and sliding
- The distinctive plasticity of the binding Quaternary and the layers in the zone of weathering that is the Opalinus clay cause a high susceptibility to settlement
- Inadmissible settlements within the partially soft Quaternary layers and the soft weathered Opalinus clay layers occur when using footings
- Second groundwater story with artesian confined groundwater is likely to cause base heave
- Possible sliding of the slope on separating surfaces
- Interference in the groundwater is not allowed and large-scale groundwater lowering is impossible for reason of settlement risk of the nearby motorway and buildings
- Swellable Opalinus clay layers cause decisive swelling liftings up to 40 mm, in case of obstructed deformation swelling pressures up to 0.4 MN/m^2 arise

1 Tunnel Offenbau - excavation stage 2 - debris disposal
2 Tunnel Offenbau - compressed air lock

Picture credits: SSF Ingenieure GmbH

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After examination of 15 variants it was decided that the tunnel at Offenbau was going to be constructed in top-down method under pressurized air:

- Pre-excavation without considerable lowering of the Quaternary groundwater level, no interference in the second groundwater story
- Construction of superimposed bored pile walls starting from an intermediate excavation
- Stepped bored pile lengths in order to maintain circulation of the groundwater in non-weathered Opalinus clay
- Construction of the cover without considerable lowering of the Quaternary groundwater
- Covering of the tunnel top
- Drilling of the tunnel under pressurized air in order to reduce the pressure stage in two excavation steps
- Partial decompression of the second groundwater storey only during short phases
- Construction of the shotcrete bottom immediately after earth excavation
- Out-let of pressurized air
- Installation of buffering layer against swelling in the final stage under atmospheric conditions
- Erection of tunnel floor
- Erection of tunnel walls
- Remaining works

First of all, superimposed bored pile walls were produced. With up to twelve boring devices at the same time, stepped bored piles with diameters of 1.20 m and a length of up to 34 m (reinforced secondary piles) were drilled at distances of 1.04 m so as to main-

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Picture credits: SSF Ingenieure GmbH

Tunnel Offenbau	
Tunnel length	1,331 m with trough north 288 m, trough south 838 m, in total 2,457 m
Covering	between 2.0 and 6.50 m at maximum
Cross-section surface of tunnel	approx. 100 m²
Bored piles	45,000 running meters
Construction period	Bored piles 12 month Tunnel boring under pressurized air 12 month Remaining works incl. emergency exit in the middle of the tunnel 12 month
Constructions	Block 1 to 7 founded on bored piles in cut-and-cover method, Block 7 to 107 founded on bored piles in top-down method, Troughs founded on bored piles
Client	DB AG (Germany railway company), represented by DB Projekt Bau GmbH PZ, Nuremberg
SSF Ingenieure	feasibility study, object planning and structural engineering

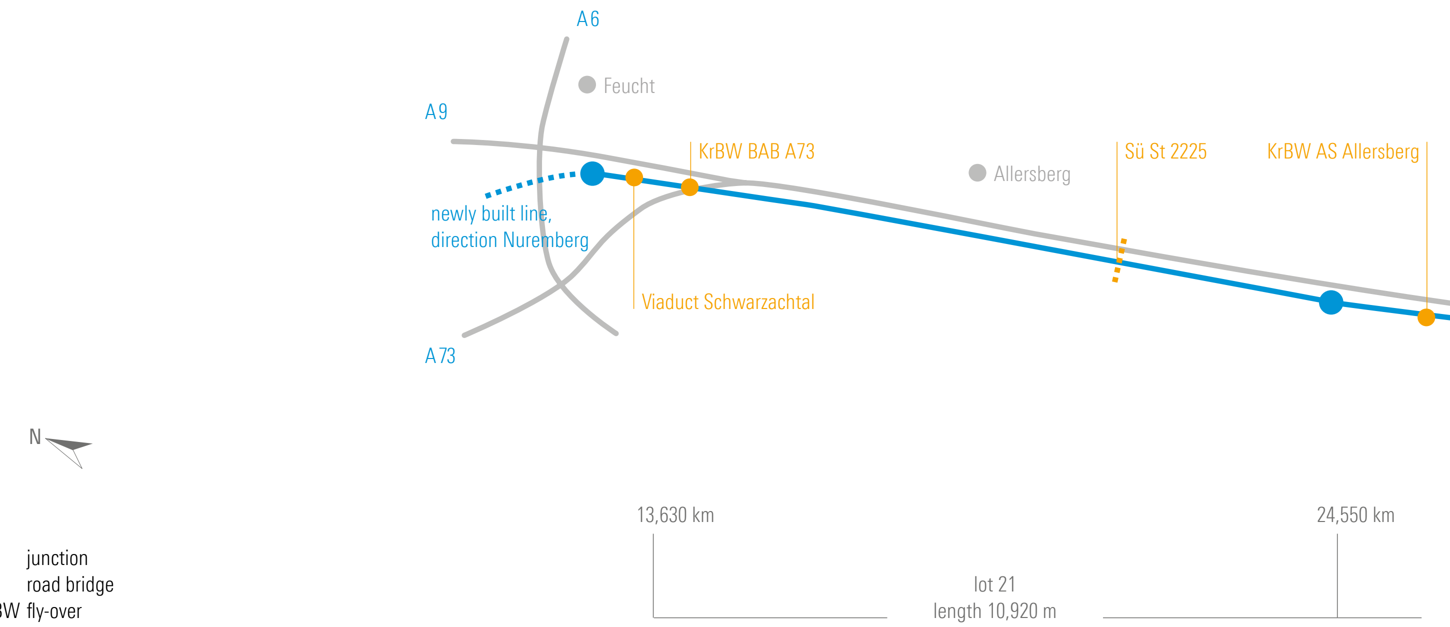
1 Tunnel Offenbau – linear construction site for bored pile walls
2 Tunnel Offenbau – interior view of tunnel shell / view to the inverted arch
3 Tunnel Offenbau – portal south including trough section

tain circulation of the groundwater within the non-weathered Opalinus clay. Sections between block 7 and block 107 were erected incrementally with regular block sections of 12.50 m and the formation of pressed joints. After insertion of the bored piles, following at about 350 m distance, the 1.0 to 1.20 m thick tunnel cover was concreted. At a distance of 600 m the finished tunnel cover sections were charged with 3.0 m earth load in order to reduce air looses from pressurized air admissions and to create a balance to the air overpressure. After a slight lowering of groundwater in the area of the southern cutting, six tunnel blocs were excavated to allow installation of the lock for workers, material and instruments.

Because of the confined groundwater underneath the insulation layer of softened clays and Opalinus clay stones, the tunnel had to be excavated under pressurized air from underneath to guarantee safety against base heave and groundwater infiltration. The required air pressure during construction depended on the pressure level of the confined groundwater within the Opalinus clay and the reached excavation level.

Tunnel boring was done under pressurized air in 2 stages. During stage 1, the tunnel was excavated until the future upper surface of the rail starting in the south and then drilled up to the northern end. A pressure level of around 0.7 bar was required for this operation. The heading situation at the southern end was implemented by a pressure bulkhead with lock installation. The north side of the tunnel was closed by a pressure bulkhead during the whole operation under pressurized air. During the second stage the tunnel bottom was excavated by individual cuts running backwards

Area map of new line Nuremberg – Ingolstadt, lot north



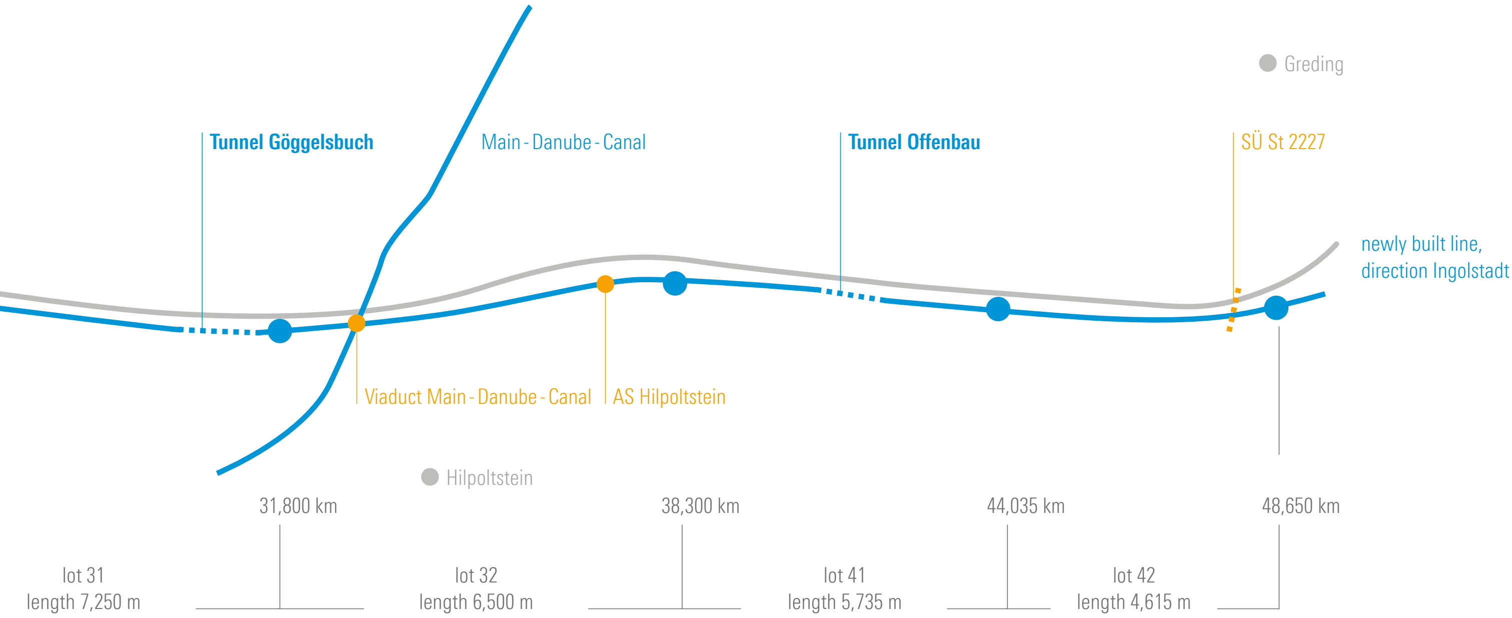
AS junction
SÜ road bridge
KrBW fly-over

from north to south under maximum pressure of 0.99 bar. The cut lengths were chosen with regards to geology and hydrology. The two-stage excavation made it possible to work over a rather long period of time with low-pressure levels and to use high-pressure levels only for the last remaining excavations.

An innovation compared to other solutions was the inverted arch which was produced immediately after excavation by using reinforced shotcrete. The inverted arch was dimensioned according to water pressure absorption due to the artesian confined groundwater and to the absorption of swelling pressure or uplift due to swelling (interation procedure according to the pliability and resistance principle).

Bored piles were stiffened directly at the foot through the inverted arch. Forces of the shotcrete bottom were inserted into the pile wall by a roughened construction joint for which the skeleton of the piles' concrete was exposed. After completion of the shotcrete shell, pressure was reduced. Further works were done under normal atmospheric conditions which simplified the construction process considerably as under pressurized air special security and health protection requirements apply, a permanent medical supervision of the workers is necessary and only tools with electric but not with combustion engines can be utilized. The groundwater decompression phase was decreased by the shotcrete inverted arch, too. A large damaging potential to the tunnel was to be found in the swelling clay-stone (Opalinus clay-stone) that the tunnel underpasses at a length of 1000 m. The swelling behaviour was analysed during laborious procedures. Occurring swelling-tensions are generally absorbed by a plastic intermediate layer. However, for the tunnel at Offenbau, an expanding clay cover of around 1.20 m would have been necessary. For that reason a buffer layer was newly developed which is able to meet the required values of tension and deformation even tough with 10 cm it is very thin. This buffer layer was applied directly above the inverted arch.

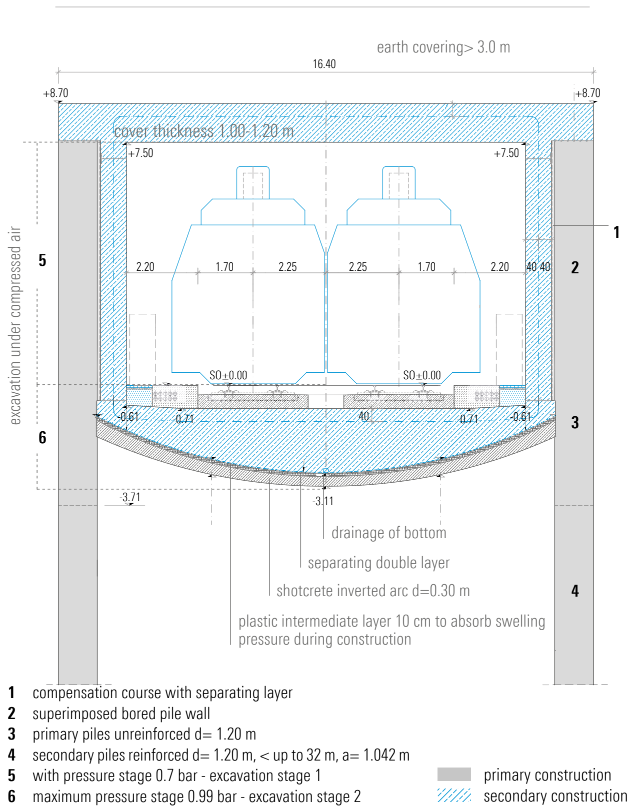
After assembly of the buffer layer, the interior fitting of the tunnel was completed. Floor and walls were constructed under the tunnel cover. The tunnel floor is directly connected to the bored pile walls by the areas with roughened construction joints. Between bored pile walls and inner walls an intermediate separating layer was assembled to decrease constraint stresses. The connection



between walls and tunnel roof was implemented by joints. In its final stage, the tunnel floor absorbs the load caused by water and swelling pressure and transmits it into the tunnel roof through the walls and from there to the bored pile walls. The bored piles form a deep foundation for the structure. The construction of the whole tunnel was realised as waterproof concrete structure with inner block joints and construction joints with joint tape as well as grouting tubes in the construction joints.

The tunnel Offenbau was completed by an emergency exit and groundwater diversion measures. At both ends of the tunnel trough constructions were built with superimposed bored piles to control durably the confined groundwater.

The largest part of the tunnel was built with watertight, enclosing walls made of superimposed bored piles. At the south end of the tunnel, six blocks on pile foundations were erected in cut-and-cover method as well as adjoining trough constructions. In the north, a trough line was built, too, for which also superimposed bored piles were used.



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