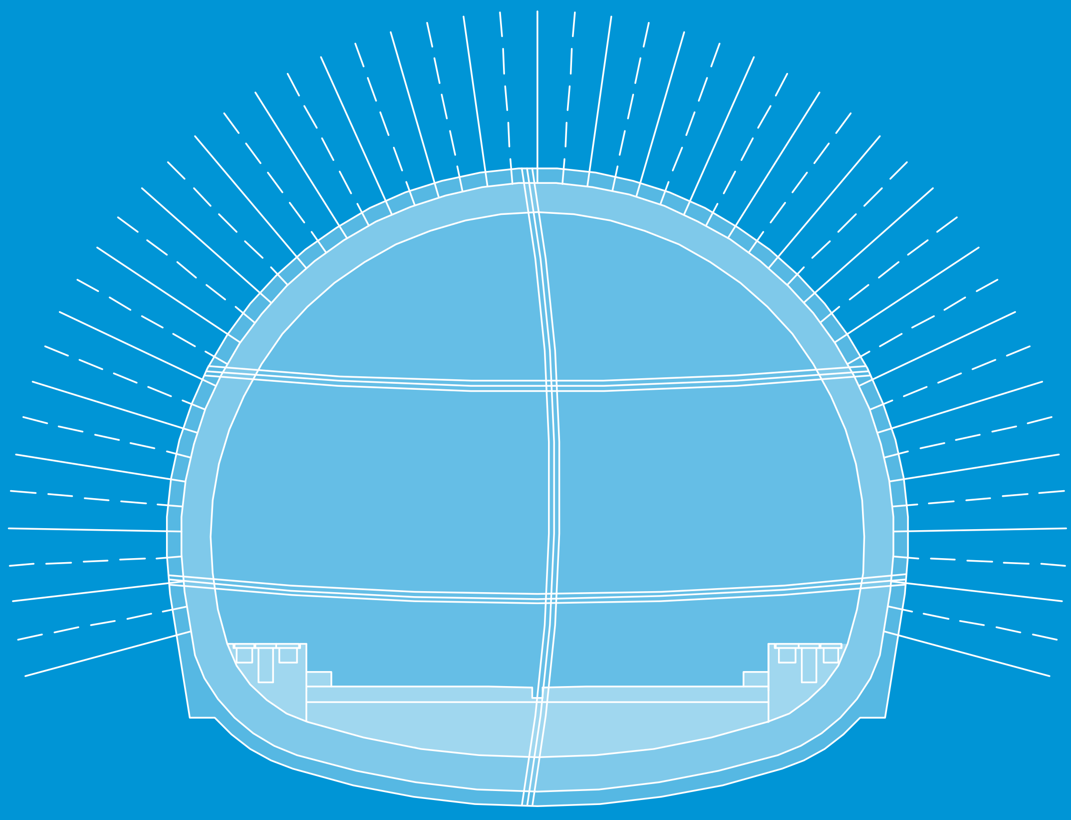
Jin Shazhou tunnel

of high-speed person dedicated railway line Wuhan-Guangzhou

SSF Ingenieure



Abstract

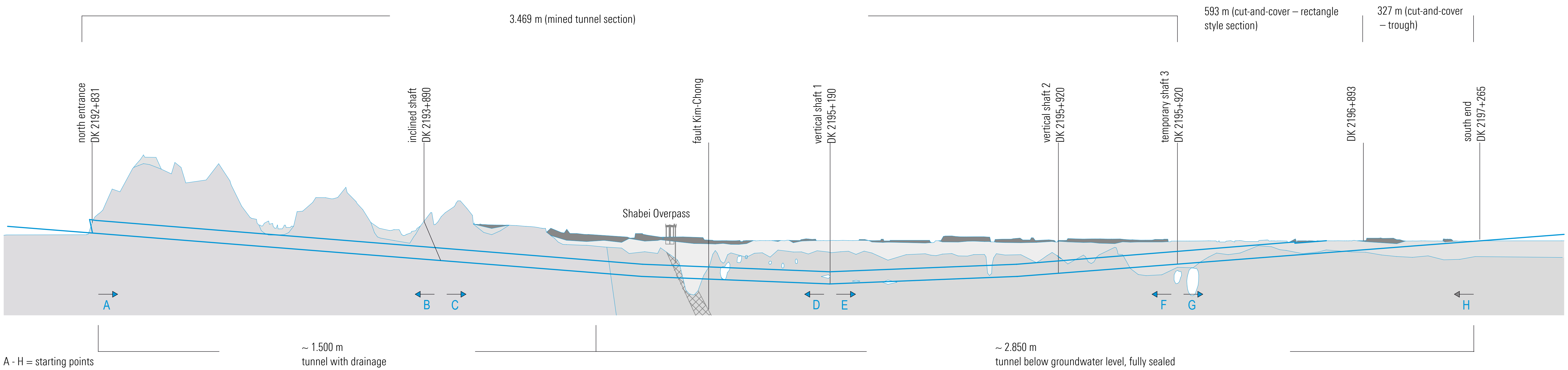
Currently, the approximately 4.5 km long Jin Shazhou tunnel as part of the Chinese high-speed railway network is being constructed. This tunnel represents one of the riskiest and most difficult tunnel constructions of China at present. The main difficulties are caused by the shallow depth with only 6 to 57 m overcovering, and the difficult conditions regarding geology and hydrogeology. Strong weathering and karstification of rock substratum, as well as the varying soil cover of the Pearl River delta plain with several – partly artesian – groundwater horizons constitute the main problems. Together with Chinese partners, German engineers of PEC+S are assigned to overall supervision and, as consultants, take responsibility in the application of internationally conventional standards regarding quality and safety.

1 Introduction

Currently, during development of the Chinese high-speed railway network, the section from Wuhan (Hubei province) to Guangzhou (Guangdong province) as part of the 2,300 km long north-south connection Beijing–Hong Kong is under construction (Figure 1). Besides some larger bridge projects, the construction of the Jin Shazhou tunnel is one of the key projects – indeed, it is one of the most difficult and riskiest tunnel constructions in China. The problems are basically based on the shallow position, the difficult and complex geology, as well as the difficult ground-water conditions. The tunnel partly underpasses settled terrain and important expressway connections with only minimal rock and soil cover (Figure 2). Due to commissioning of the entire railway section at the beginning of the year 2010 in Guangzhou, the construction measures have to be finished under an enormous time pressure. The German company PEC+S (Munich), a cooperation of the engineering offices SSF Ingenieure, Gauff Rail Engineering, and other partners, has been assigned to overall supervision within a joint-venture contract together with Chinese partners. On the one hand, PEC+S is supposed to guarantee the compliance of Chinese regulations regarding safety and quality requirements, on the other hand, one of the main issues is consultancy of supervision, client, and construction company. Thus, besides information and instructions during construction site inspections, written comments and short expertises are worked out. They refer to current details of problems. Another key issue ist the annotation and awareness of hidden danger potential, at which in extreme cases construction works can even be stopped.

1 Overview of Wuhan – Guangzhou passenger dedicated line

2 Longitudinal section tunnel



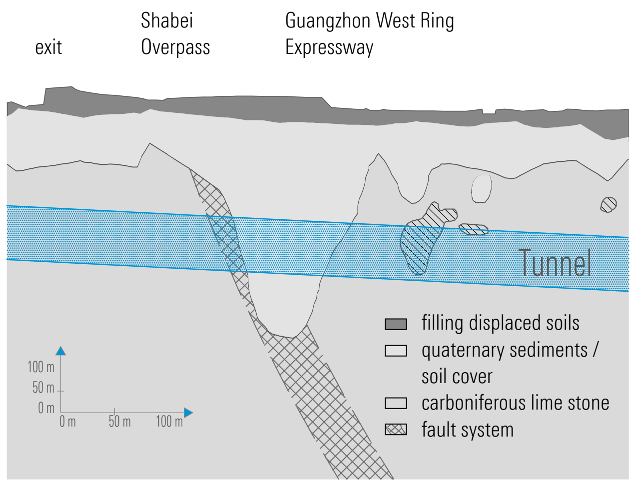
2 Geographical situation

The entire Jin Shazhou tunnel is situated in the area of Nanhai City northwest of Guangzhou (Guangdong province). The north entrance is situated in Zhou village (Liushi Town, Nanhai City), the south exit in Shaxi Village (Huangqi Town, Nanhai City). The northern part of the tunnel crosses a hilly chain (maximum height 83 m NN) in the delta plain of the Pearl River (average 1-3 m NN). The whole southern part is situated in the delta plain and partly runs parallel to the Guangzhou West Ring Expressway, and undercrosses the last one in the area of the connection to the Guangzhou-Foshan Expressway, as well as below a big toll station with a multi-lane exit over a bridge. The bridge foundation is immediately influenced by the tunnel construction. On ground surface, the tunnel line is repeatedly crossed by the heavily frequented expressway and some subordinate roads. The area along the tunnel line is mainly used for agriculture and is sparsely populated. There are some large fish ponds exactly above or near the line. The project area is situated south of the tropic of cancer in the subtropical monsoon belt and shows perennial warm and humid climate. The amount of rainfall varies according to seasons, but is generally high with annual average values between 1,213 and 2,257 mm. This results in strong and deep weathering. The water level of the small tribuaries to the Pearl River, as well as the connected ground-water levels also vary in the different seasons. Due to the low gradient of 1 to 5 % flow velocity is low. Drainage direction is generally from north west to south east towards the Pearl River.

3 Geological-tectonical overview

Hard rock geology of the project area is dominated by 2 main units, which are overlain by young Quaternary sediments of the Pearl River delta. The oldest unit comprises Upper Devonian sedimentary rocks of the Maozifeng formation (D3m). They mainly consist of shallow marine siltstones and shales with thin layers of arcosic sandstones and graphitic limestones. Different weathering grades are the reason for the multi-coloured appearance and the varying geotechnical behaviour within the series. All in all, the rocks of the Maozifeng formation are only slightly water-bearing and only slightly permeable.

The Devonian is overlain by rocks of the Lower Carboniferous Datang formation (C1d) which is divided into 2 groups. On the one hand, it consists of an interlayering of gray to black shales with siltstones, sandstones, and graphitic limestones (C1dc), on the other hand a mainly calcareous series (Dengkou limestone, C1ds) has been developed. The last one comprises graphitic limestones with minor shale and siltstone intercalations. It dominates the Carboniferous succession along the tunnel line. The Dengkou limestone is affected by a highly developed karstification with solution-widened joint systems and caves with dimensions from 0.1 to 5 m, sometimes up to 23 m. This water-bearing karst system shows strong flow rates, near the surface the karst caves are often additionally filled with water-saturated plastic clays and fine sands. The Quaternary (Holocene) soil cover with sediments of the Pearl River delta plain is prominent south of the hilly chain and especially in the area of the open excavation (see below). It reaches thicknesses between 0 and 43 m dependent on the relief of the underlying rocks. The largest thickness can be seen in the area of an old, refilled erosional structure. The rich sedimentary history of the Quaternary results in an extremely varied composition from water-saturated, flowable muds, weak plastic clays to silty sands and coarse-grained quartz sands. Accordingly, the geotechnical characteristics are extremely different and varying, too.



3 Longitudinal section Kim Chong - disturbance

With an overall tectonic regard, the project area belongs to the South China fold belt which is mainly characterized by 3 large tectonic fault groups:

1. originally, Lower Paleozoic (Caledonian) east west striking fault systems which are not active now,
2. Mesozoic (middle Yanshan phase) northeast striking faults of the Canton system
3. Cenozoic northwest striking faults, like the Hualong-Nansha-fault.

In local context, the tunnel crosses a northeast striking anticlinal structure (with Devonian sedimentary rocks in the centre and Carboniferous cover series) within the Lane elevation, which is developed between the Canton fault system and further 3 subordinate fault zones. Seismicity in the area is relatively low. According to exploration results, the largest influence on the tunnel structure has the Kim Chong fault which belongs to the Canton system (Figure 3). It obliquely crosses the tunnel within 50 m length, and comprises strongly diminished tectonic breccias. The above-mentioned erosional structure runs along this fault zone. As a common feature of all crossing fault zones, their width increases with depth and, therefore, can influence the tunnel structure enormously.

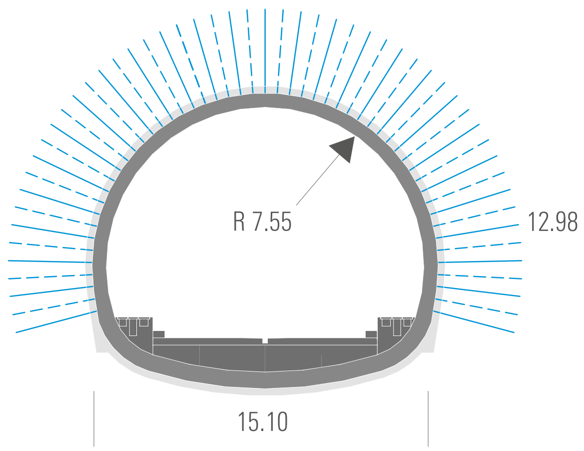
4 The project

The Jin Shazhou tunnel (start of construction: September 2006) comprises a 3,464 m long, conventionally constructed tunnel section (Figure 4) with a minimum of 6 m and a maximum of 57 m cover thickness and a 1.000 m long section with open excavation (cut-and-cover-construction) with tunnel and rectangle style (Figure 5) and open trough.

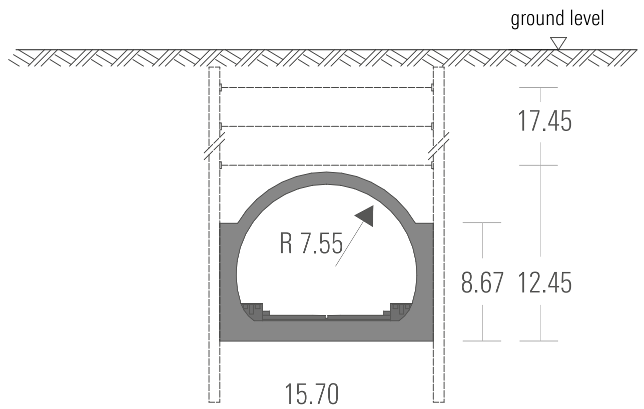
According to the Chinese chainage with regard to the Beijing-Hong Kong line, it extends from DK 2192+836 (north entrance) to DK 2197+300 (south end of open trough).

The tunnel runs straight and will be developed with non-ballast track for high-speed trains (design speed 350 km/h). After finishing, the cross section will be 100 m^2 and a diameter of 12.6 m. The maximum width of excavation is at 15.10 m on the average. The tunnel shows a V-type profile in longitudinal direction with a maximum inclination of 20 ‰.

The conventionally constructed tunnel part is started from 5 starting points with 8 advances (Figure 2). From north entrance (Figure 6) at DK 2192+836 and from a temporary shaft 3 at the transition to the open excavation section at DK 2196+300 (constructed to accelerate the works), the construction is done from

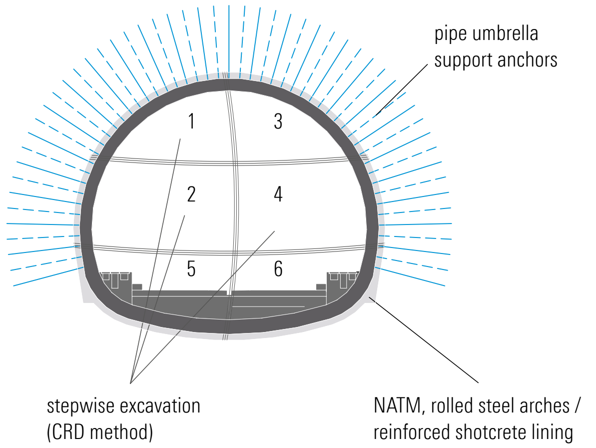


4 Cross–section mining method

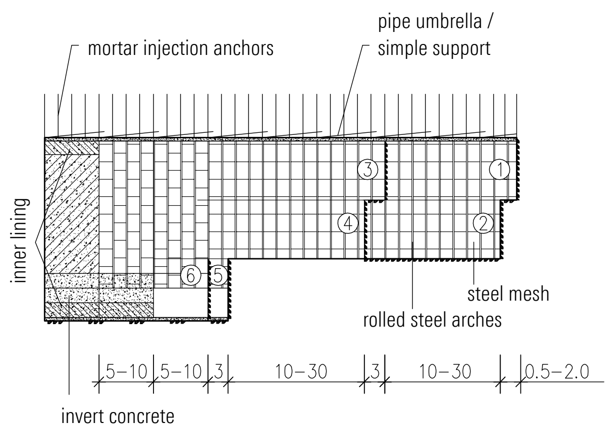


5 Cross–section cut-and-cover method

6 North entrance Jinsha Zhou Tunnel, beginning of construction 2006



7 CRD method with 6 advance faces, cross-section



8 CRD method with 6 advance faces, longitudinal section

one side. Starting from an inclined shaft at DK 2193+890 and 2 vertical shafts (vertical shaft 1 at DK 2195+190, vertical shaft 2 at DK 2195+920) excavation is done in both directions. The largest part of the Jin Shazhou tunnel lies within or below ground-water level. Furthermore, the deepest point is situated near the middle of the tunnel. Therefore, waterproof and dewatering measures are of highest importance. Pumping stations will be installed at DK 2195+190 (deepest point at vertical shaft 1) and at DK 2196+889.

The inclined shaft has a total length of 235 m and meets the main tunnel at DK 2193+943. Vertical shaft 1 is 40.4 m deep with a cross section of 15.5 x 7.0 m, vertical shaft 2 reaches 24 m depth with the same cross section. In order to save time due to difficult geological conditions, temporary shaft 3 with 18 m depth has been constructed as late support measure at the transition from open excavation section to the mined tunnel section (Figure 12).

4.1 Conventionally mined tunnel advance

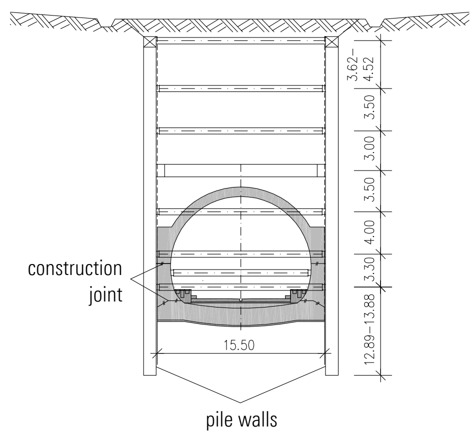
According to geology, the Jin Shazhou tunnel is excavated either by blasting technique or by excavator (Figure 8). It is remarkable that despite most difficult geological and hydrogeological conditions only conventional advance methods are being used. Although the Jin Shazhou tunnel mostly runs in or below groundwater level, Chinese constructors avoid advance methods like compressed-air advance or soil freezing. Besides the mainly applied methods in Europe (like normal bench-method or side drift advance at difficult conditions), the widely spread use of the CRD method in China has to be mentioned (staggered sectional advance with enhanced temporary lining for each of the 6 advance fields (Figure 7,8,11).

The base for the mining advance is the New Austrian Tunneling Method (NATM) with stepwise excavation and reinforced shotcrete lining. Basically, the initial lining consists of rolled steel arches, steel mesh, mortar injection anchors, and fibre shotcrete (Figure 8,14). Based on the Chinese rock classification, suitable modifications of advance method (2-bench-, 3-bench-, CRD method), as well as the scale of support are chosen. Since this classification, based on the preceding exploration drillings, can only give a rough classification of sections with general rock quality, it is of high importance to react to local and short-term changes of rock conditions. Therefore, in case of better conditions, unnecessarily strong reinforcement and higher cost and time can be avoided. On the other hand, in case of conditions getting worse, the risk of deformation and collapse due to insufficient lining and support measures can be minimized. In this context, consultancy by the foreign engineers resulted in significant improvement. Changes

9 High-pressure injections near vertical shaft 1

and adjustments of advance method and support measures are laid down in meetings arranged by the client on short call, normally attended by the construction company, supervision unit, as well as design company. This procedure results in sustained flexibility and leads to faster reactions to present conditions, and, therefore, to an obvious improvement of safety.

Depending on the geological conditions, round lengths reach from 0.5 to 2 m. In bad geology, advance head supprt has to be installed, mainly injection ductules and pipe roofs with different



10 Cross–section with support measures open excavation

pipe diameter and up to 80 m length. Temporary inverted benches with steel arches and concrete are installed in sections with stronger arch head settlement and convergency.

For geological forecast mainly geophysical methods are used (TSP, HSP, georadar, infrared measurement), further supported by 3 standardized exploration drillings with 30 m length from the advance face. Number and orientation of forecast drillings have shown to be insufficient in strongly karstified sections, especially in areas with near-surface karst, where the excavation crosses the irregular boundary between rock and overlying loose material. This deficiency is compensated by additional forecast drillings. One of our points of criticism regarding forecast was the lack of an experienced tunneling geologist. Engineering geological documentation and interpretation are being done by the responsible engineer in the advance section, and conforms with the minimum reqirements of Chinese codes. Compared to European standards mostly there is no continuously accompanying geological recording.

Only the northern part of the Jin Shazhou tunnel is developed as a drained tunnel for 1.5 km length (Figure 2). The remaining part runs below groundwater level and, therefore, is constructed as fully sealed, undrained structure. Therefore, the requirements for waterproof measures are correspondingly high. These measures comprise an outside drainage with annular and longitudinal blind pipes, and waterproof plates with geotextile base. Construction joints of the 2nd lining are additionally sealed with rubber joint tapes or swellable joint stripes. Due to the present hydrologic-hydrogeologic conditions exact placing and best processing are of highest importance. As an accompanying measure, overlapping mixing pile walls are installed in some critical sections to minimize groundwater inflow as well as support measure against the partly neighbouring expressway embankment. For additional stabilization, the construction ground is supported by high-pressure injection from ground surface. The amount of injections is exceptionally large compared to European application, partly up to more than 20 injection equipments are in use at the same time (Figure 9).

4.2 Open excavation

The open construction pit cuts through the partly groundwater bearing soil cover down into the weathering zone of the underlying rocks. Excavation of the up to more than 20 m deep pit is protected by both-sided pile walls. The pile walls consist of up to more than 27 m deep, reinforced drilling piles with 80 cm diameter and 1 m axial distance. The space between the piles has been largely sealed against groundwater inflow with a second layer of mixing piles behind with 65 cm diameter. Temporary support during construction has been done with up to 5 layers of steel tube brackets (Figure 10).

The cut-and-cover-construction reaches 450 m length with tunnel cross section and 140 m with rectangular cross section. In connection to the cover, another 30 m of the open excavation are supported by concrete brackets, the rest of 380 m are constructed as open trough. Due to cutting through the uppermost groundwater horizon, the basal concrete of the southernmost section has to be protected against uplift with uplift piles.

During construction, one of the most important factors is the protection against water access and circular flow respectively into the pit base by pile walls. In most cases, such water accesses are combined with material inflow. This produces a mass deficit outside the pile wall, which can lead to settlement and even smaller collapses. Additionally to waterproof measures within the construction pit, groundwater lowering by outside situated pumping wells is being done.

In the open excavation section, highest quality of the waterproof measures of the 2nd lining is demanded, too.

4.3 Tunnel constructional problem zones

In the entire tunnel section, three zones turned out to be critical. The reasons basically originate from the shallow position of the tunnel. In detail, the reasons for different difficulties for each section vary.

The first geotechnically difficult section is the connection between temporary shaft 3 and vertical shaft 2 (Figure 2). On the one hand, the advance crosses the boundary between rock and soil cover, on the other hand, the loose soil sediments react very sensitively to water access and settlements. Initial ground surface settlements of more than 60 cm and arch top settlements of more than 50 cm required a change of the advance method to CRD method. The excavated working areas are protected by a pipe roof, soil stabilization from ground surface is done with injections and mixing piles down to 5 m below arch head. Pipe roof lengths of up to 80 m are used; this length is quite commonly used in China. However, it is a disadvantage, because drilling accuracy and the distance between the single pipes cannot be kept in the same way as with shorter pipes. Therefore, due to possible deviations, the arch function between the pipes cannot be fully guaranteed. Time pressure forces the Chinese construction company partly to continue with this big length. In spite of time constraints the implementation of all single steps of the CRD method must be guaranteed to attain the maximum temporary support function. Exact implementation is a great challenge to the German and Chinese supervision, because the construction company only partly fulfills the requirements of CRD method due to time pressure. The section between

11 CRD method temporary shaft 3

12 Mining by manpower in temporary shaft 3

temporary shaft 3 and vertical shaft 2 is additionally supported by comprehensive high-pressure injections (soil-fracturing) from ground surface against settlement and water seapage. Injections reach 5 m below tunnel crown. In the heading face of the tunnel the efficiency of these high-pressure injections can be repeatedly proved textbook-like.

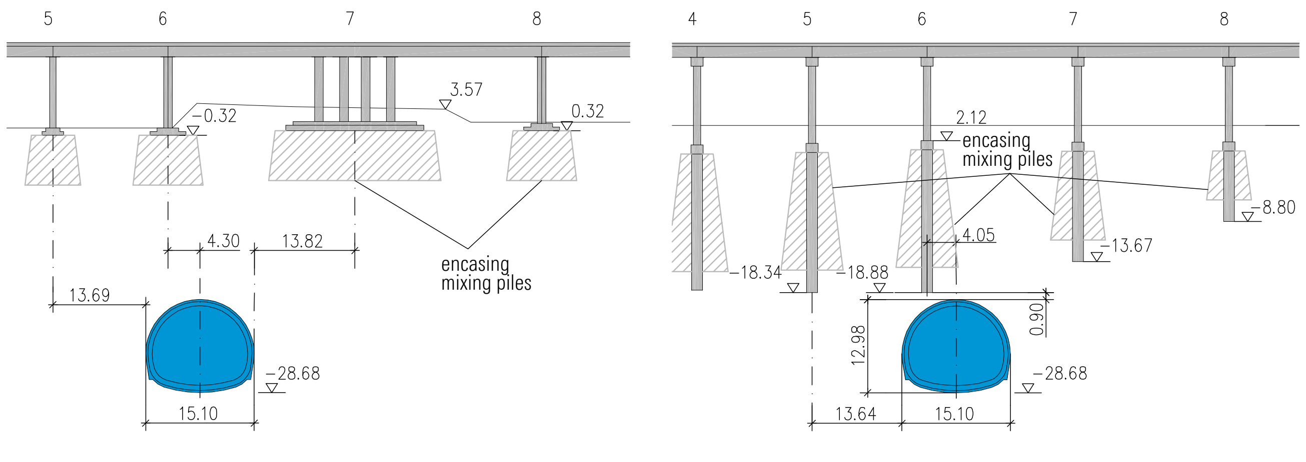
The second problem section concerns the entire area between the north advance of vertical shaft 2 and north advance of vertical shaft 1. This section runs through strongly karstified limestones of the Lower Carboniferous. The karst structures contain varying water amounts, their near-surface position often results in infilling with water-saturated loose soil material. Due to karstification the boundary of the limestones and the soil cover is very irregular. Isolated bodies of artesian water occur frequently in depressions of the rock surface. This boundary is also often randomly crossed by the tunnel, which leads to unexpected inflow of water and soil material. In single cases, this even leads to collapses. Only after enhancing geological forecast with drillings and TSP, these problems could be solved. The third challenge regarding tunnel constructional technique is an erosional structure between vertical shaft 1 and inclined shaft. This structure is filled with soil material, and must be crossed by the tunnel within 150 m length. The advances arrive from both sides out of karstified limestone and cut through the boundary to the soil material (mainly sandy silts and clays), which is most likely water-bearing and in every case sensitive to settlement. CRD method will also be applied in this section, to underpass it most gently and without larger settlements. Stability of the heading face must possibly be guaranteed by advance face injections. As an additional problem, exactly in this critical section the tunnel undercrosses the expressway and a bridge of the expressway exit. Furthermore, the bridge foundation is not uniform and is situated in the immediate area of influence of the tunnel construction. One part of the bridge is founded with divided shallow foundations, a later extension is founded with friction piles. The deepest friction pile approximates the tunnel lining to only 86 cm and is located only 4 m outside tunnel line. During tunnel excavation and every construction measure on the bridge, the traffic flow must continue. For safety reasons, a temporary overpass has been planned by the client and the design institute to ensure the exit from the expressway. Subsequent measures will be decided according to actual conditions.At this key position (Shabei overpass), a massive package of measures will be applied to assure stability of the underpassed roads and bridge structures despite expected settlements. The area of the expressway is supported by comprehensive ground surface injections (rotary-jet piles). Mixing pile walls on both sides of the tunnel are installed in order to minimize water access. For protection of the expressway bridge, their foundations are additionally supported by encasing mixing piles (Figure 13). The German bridge and tunnel engineers of the supervision unit contribute their part with alternative and improvement suggestions to enhance safety and to minimize time and cost expense. When offering alternative solutions, it must be guaranteed, that they are exactly adjusted to the current conditions and possibilities. Measures which need highly specialized equipment and personnel are not suitable without sufficient time for preparation. However, pragmatic solutions that can be applied with the available personnel are welcomed by our Chinese partners.

5 Résumé

The difficult conditions of the construction of the Jin Shazhou tunnel as well as the enormous time pressure require highest demands on the performing construction company as well as the supervision. The involved Chinese engineers are highly educated, but the training of the mostly unexperienced workers is a big challenge. There is also a certain potential for further development regarding accompanying geological documentation and forecast. Although Chinese tunnel construction codes already meet international standards, their implementation could be improved. Repeated trainings in the starting phase of the project could improve the awareness regarding the importance of relevant codes and measures. Therefore, due to the language barrier and the different mentality of the Chinese engineers, communication demands a lot of intuition and diplomacy from the German engineers every day.

Nevertheless, despite all problems, positive experiences and impressions prevail during accompanying such a big project in responsible position, in which more than 1,000 km of railway line, among it 165 km tunnels, will be constructed in less than 3 years. This especially refers to the pragmatic solutions, which are found again and again by the construction company as well as the German and Chinese supervisors. We also want to highlight the good cooperation with the construction company, the Chinese supervision, and especially the client. All related parties act unanimously to finish this difficult tunnel safely and without accidents, in time and in high quality.

13 Foundation improvement of Schabei overpass bridge



14 Two-bench mining in Devonian quarzites with invert reinforcement near the north entrance

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