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Koralmbahn-Challenges and solution concepts for the realization of the lot KAT 3 of the Koralm Tunnel with a major focus on different geological conditions with reference to the specification of the shield machine

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1. Abstract

Project
The Koralmbahn is one of the largest rail infrastructure projects in Europe. It is an essential key project in the Baltic Adriatic Axis within the Trans-European Networks. The Koralmbahn crosses the Alps in the east over a distance of 127 km in the south-eastern part of Austria. The double-track electrified new line is established for a maximum line speed of 250 km/h and includes 15 stations and eleven tunnels including the twin-tube Koralm Tunnel with a total length of 32.9 km. With the award of the construction works for the last of three construction lots (KAT 1-3) of the Koralm Tunnel, a further decisive step towards the realization has been completed.

The lot KAT 3 sets high demands on the technical implementation and will, after realizing, greatly expands the current state of technology by using innovative solutions. The technical challenges are characterized by excavation of highly changeable heterogeneous geology of loose rock (neogenic section in contract KAT 3) to hard rock zones (crystalline section in contract KAT 3), interrupted by fault zones (Lavanttal main fault zone). With the EPB machine concept an aligned shield machine cuts through loose rock areas. As a hard rock machine it cuts through crystalline structures. Operational considerations (low maintenance as possible) led to the execution of a single-layer construction with segmental lining for resisting water pressures up to five bars. In the case of even higher pressure, a new pressure limiting system is used.

The tunnelling and machine data are constantly monitored by process controlling for the purposes of the project in terms of quality, construction time and costs.

Overview

For the tunnel there is a soil related machine concept in combination with the applied construction method, whereas the extension of the current state of technology is defined by a comparison previously practiced solutions.

The Koralm tunnel length is about 32.9 km. The tunnel is divided into three contracts, which will mostly be driven in a continuous process (contract KAT 2 in Styria, contract KAT 3 in Carinthia). The excavated cross-section of the tunnel is about 82 m². To consider the European safety standard (TSI), the two parallel single-track running tunnels will be linked over the whole distance every 500 m with connecting tunnels and an additional emergency exit approximately in the middle of the tunnel.

In order to obtain detailed geotechnical knowledge for the planning of mechanical tunnelling, extensive exploration measures were undertaken in the area of the top heading of the later southern bore.

To achieve representative cover of the geological conditions, a shaft was build at Paierdorf (blue part in Fig. 1) in the section of contract KAT 3 with deep overburden in addition to the starting points with shallow overburden (West portal, intermediate starting point at Mitterpichling as orange part in Fig. 1). The investigation tunnel at Paierdorf was excavated in both directions from this shaft. The top heading, with a clear excavation area of approx. 40–50 m², was excavated in the neogenic and through the fault zones with a temporary top heading invert.

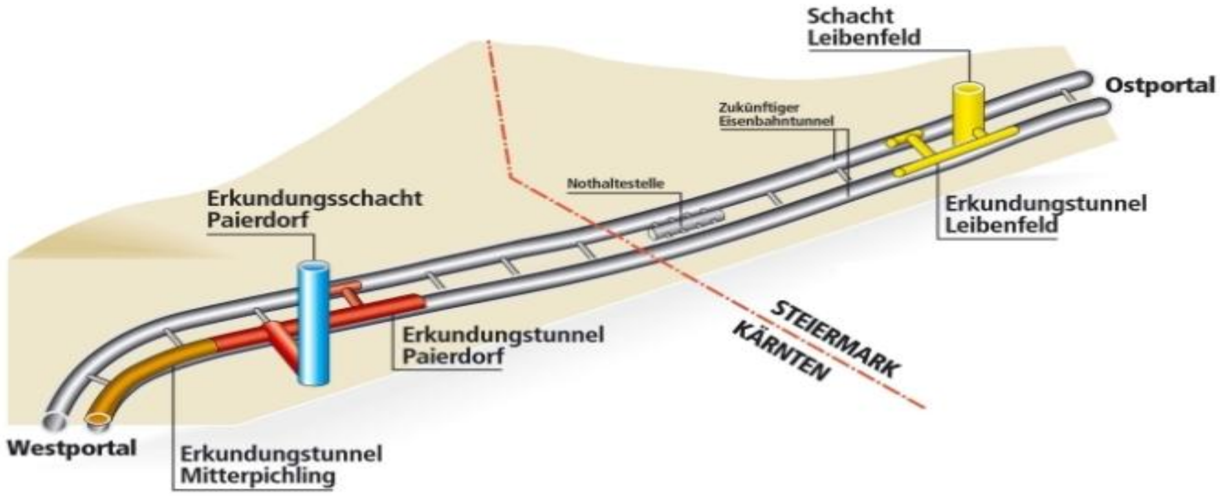

Fig. 1 Schematic project overview of the Koralm Tunnel showing the investigation works and the contracts KAT 2 in Styria and KAT 3 in Carinthia

The transition from the neogenic to the crystalline, which is marked by a pronounced fault tectonic, the Lavanttal main fault zone, was the main focus of investigation for contract KAT 3. The tunnelling work undertaken during the investigation programme is completed and was mainly focused on the Lavanttal main fault zone and the crystalline section of the Koralpe.

Challenges of the Koralmbahn lot KAT 3

The biggest challenges are the different geological situations the tunnel goes trough. The transition from the neogenic to the crystalline, which is marked by a pronounced fault tectonic, the Lavanttal main fault zone, was the main focus of investigation for contract KAT 3.

Figure 2 shows the three main challenges of KAT 3 where a special machine concept must be chosen. At KAT 3 a special shield machine for a single shell solution with segmental lining is used. The TBM operates as a shield machine with an earth pressure concept in the neogenic part, which extends about 4 km followed by the 0.47 km long Lavanttal main fault zone. For the next section the machine is coupled on a hard rock TBM-S machine, with a modified cutterhead. This type operates in the crystalline part, with al length of 7.6 km.

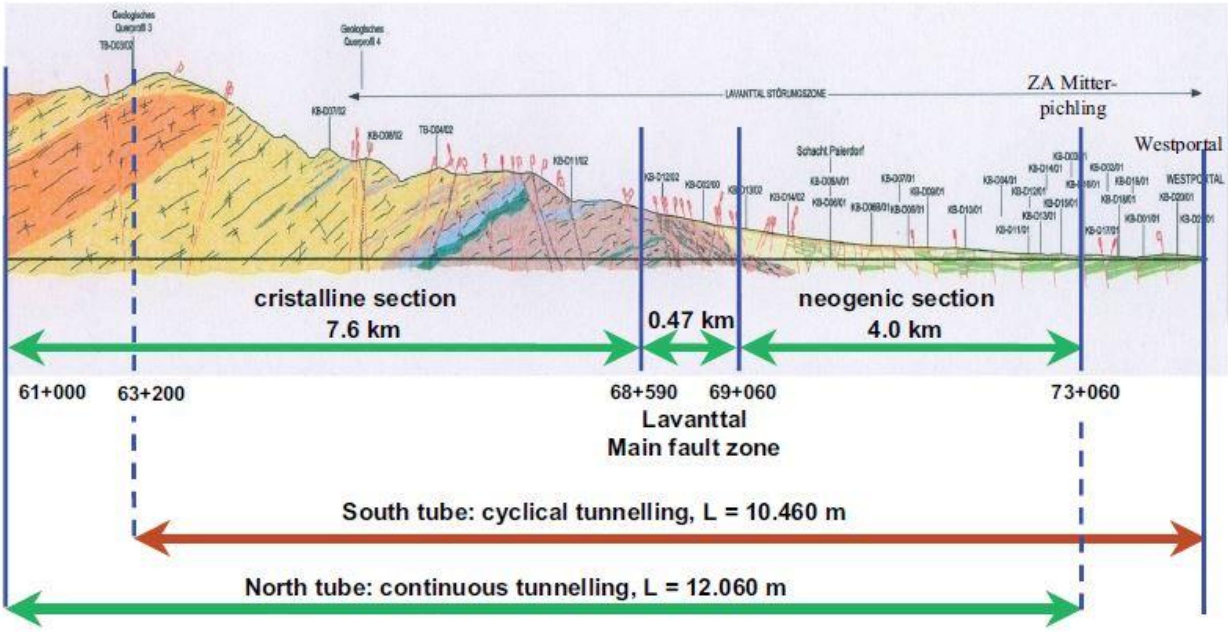

Fig. 2 Geological profile of contract KAT 3

2. Introduction for Geology

The project area is located in the crystalline complex of the Koralpe, with partly tectonic contact to Miocene sediments of the basin of Lavanttaler adjacent to the west and in the east also dives under Neogene deposits of the West Styrian Basin. The rock units are covered over wide ranges by Quaternary sediments.

Quaternary
- top layer
- quaternary gravel
- debris and alluvial fan

Neogene (Miocene)
- Schwanberger block gravel
- silt
- sand
- gravel
- silt/clay/Tonmergelstein, low solidified
- sandstone, low solidified
- alternation of silt/clay/Tonmergelstein – sand/sandstone, low solidified
- conglomerate, low solidified
- fault rocks (Neogene)

Crystalline
- mica schist - gneiss shale sequence
- Plate gneiss sequence
- fine-grained gneiss sequence
- Coarse grain gneiss sequence
- Marble sequence
- Amphibolit sequence
- Fault rocks (crystalline)

<u>Neogenic section in contract KAT 3</u>
During the investigation of the section approx. 4,000 m long through the neogenic (Fig. 2), very densely bedded silts, sands and gravels with soil character were encountered. Also the siltstone, claystone and sandstone, strata with low rock and tension strengths has to be discovered. For temporary support, a relatively stiff construction was chosen, which proved to be adequately load-bearing. The experiences from the tunnelling work show that the ground is very sensitive to the effect of water. The shear strengths are greatly reduced or disappear completely. Where groundwater table is up to 110 m above the crown of the tunnel in places, tunnelling work was made possible by drilling systematic advance drainage holes with filter tubes in the permeable to mostly weakly permeable neogenic strata in order to relieve the pressure. Particularly in geologically and hydrogeologically poor ground conditions, the use of vacuum lances was imperative. This means that the later mechanical boring of the north bore can assume almost continuous drained conditions nearly without pressure.

Lavanttal main fault zone
Next to the neogenic section, the tunnel passes through about 470 m of the Lavanttal main fault zone (see Fig. 2).The fault zone is characterised by a heterogeneous composition of soft plastic, fine-grained and coarse-grained cataclasites and also competent rock slabs. The thickness of the cataclasites ranges from a few metres to many tens of metres. In this section of the Lavanttal fault zone, squeezing to strongly-squeezing ground conditions were encountered in some stretches, which made the implementation of a stiff support concept impossible relating to overburden depths of up to over 260 m. In order to avoid overstressing and resulting failures in the shotcrete lining, a yielding support system was used for a total length of approx. 160 m with deformation slots in the spring line supported by yielding steel elements.

Crystalline section in contract KAT 3
This last section in solid rock, crystalline, just forms the central area of the Koralpe. This mostly consists of little faulted solid rock with strongly to extremely abrasive rock types, deep mountain overburden of up to 1,250 m and high water pressure in some places. About 7.6 km of contract KAT 3 runs through the crystalline. Water ingress is normally associated with regions of strong faulting, fractured zones or fault sand. But due to advance drainage the water was mostly collected and drained away during the excavation of the investigation tunnel.

3. TBM-concept at KAT 3

The TBM-concept for KAT 3 can be split into the continuous tunnelling and the cyclical tunnelling. The continuous tunnelling will be applied at north bore and the cyclical tunnelling will be applied at the south bore.

The design work for the north bore of contract KAT 3 was based from the beginning on the concept of continuous tunnelling. The experience from the investigation tunnel, while passing through the Lavanttal main fault zone, delivered significant discoveries. The length of the Lavanttal main fault zone of 0.9 km based on the results of the preliminary investigation turned out to be actually only half the estimated length according to the geological documentation and geotechnical measurements produced during the excavation of the investigation tunnel. The tunnelling concept, derived from this experience, plans a shield machine with earth pressure components to enable active support of the face where required for tunnelling through the neogenic section and the Lavanttal main fault zone. The crystalline section has to be tunnelled in hard rock mode after rebuilding the machine. The exact location for rebuilding remains to be decided during further design work.

The tunnelling concept for the south bore in those sections already excavated for the investigation tunnel only requires enlargement to the size of the full profile. The remaining, unexplored sections in the crystalline will be excavated by drilling and blasting in competent rock, up to the contract boundary. Advance drilling will serve to thoroughly drain the rock mass, and will be supported by the application of vacuum where required as a preventative measure, or in fault zones. The choice of support elements for possible branches of the Lavanttal main fault zone is based on the experience from the investigation tunnel and plans the installation of deformation slots and yielding elements.

Basic concept of shield machine
The basic requirements for the structure of the shield machine (TBM) specify for both, the neogenic and crystalline sections, the shortest possible tapered shield. At the third points of the shield, injection holes will be distributed around the perimeter in order to be able to inject lubricant like bentonite or grease to reduce friction. This measure should keep the friction resistance low or reduce it in order to counter squeezing during tunnelling. The cutter head has to be flat (Fig. 3) with the smallest possible proportion of openings in order to enhance mechanical face support and to activate support resistance as soon as possible. A circumferential closed rim should minimise tearing into the rock mass and help avoid the face being cut away in advance. Discs in the gauge area will make overcutting possible. It

should be possible to adjust the overcut to suit the geological conditions with a hydraulic mechanism or by shifting the discs. A jointed cutterhead bearing should also make eccentric overcutting possible. Additional stabilisers have to be designed to stabilise the attitude of the machine (rolling), to improve the steering and to increase the thrust force. It must be possible to drill through openings in the shield skin and free areas in the cutterhead for purposes of advance investigation, drainage or grout injections.

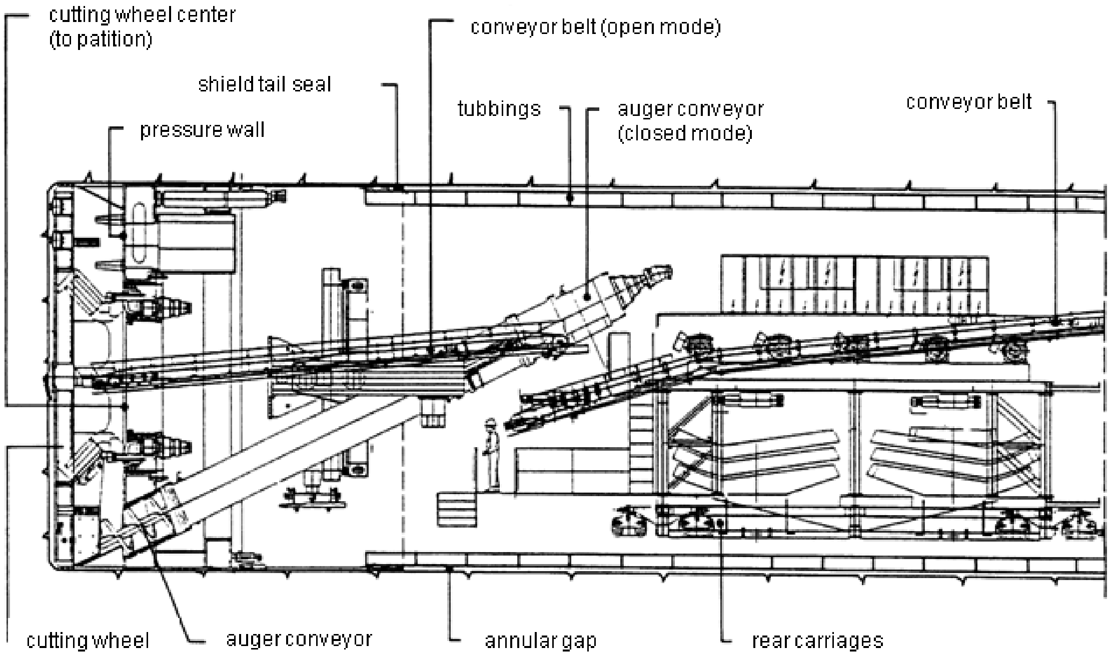

Fig. 3: TBM-concept for the neogenic part (Shield machine with earth pressure components)

Long stretches of the tunnel in contract KAT 3 have been evaluated as stable rock, or only overstressed near the cavity. For reasons of logistics, construction practicalities (ventilation) and particularly also for economic reasons, the intention is to build the Koralm Tunnel with a "single lining", which will be constructed as a segment lining 35 cm thick. As long as there is no requirement for geotechnical or structural reasons, the subsequent construction of an inner lining can be omitted. In faults, which are of relevance for construction, a waterproof inner lining has to be installed as standard.

The standard section (Fig. 4) is therefore designed for the optional installation of an inner lining and has been optimised from the points of view of operational, construction and structural requirements (feeder rail, drainage system, signals, communications and power supply equipment). The entire tunnel will be constructed with relief from water pressure, which will be achieved by systematic drainage drillings through the segments. The segment sealing gaskets will therefore only be subject exposed to slight hydrostatic pressures.

In geological conditions, where insufficient stabilisation of the segments can be provided by the stowing of pea gravel or mortar grouting, the annular gap will subsequently be systematically filled or grouted in order to prevent the sealing gaskets recovering, which are compressed by the thrust force. For geotechnical very highly loaded stretches, or in faults that are significant for construction, special segments are planned with a higher area of reinforcement and higher concrete strength. As a further measure, a water proof inner lining can be installed. When the inner lining is not required, more stringent requirements are applied on the production tolerances of the segments and their installation precision, compared to requirements of a two-lining system.

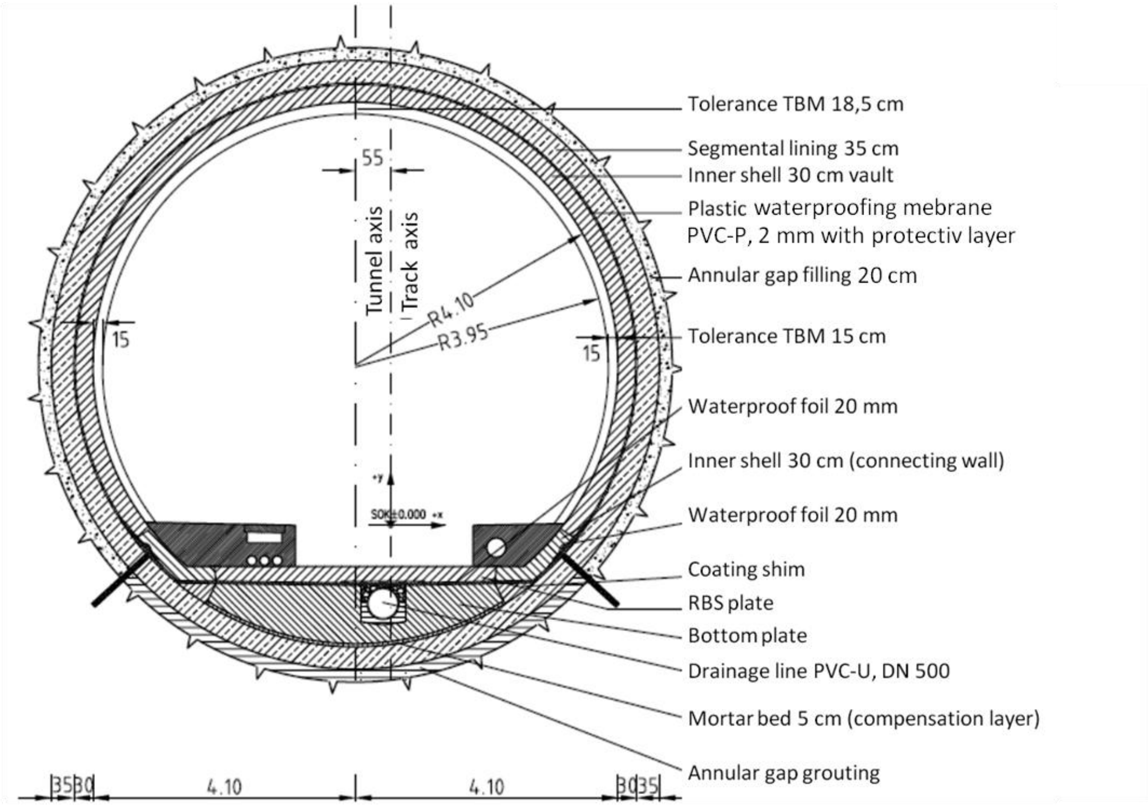

Fig. 4: Standard section for continuous tunnelling

Logistic
In account of the length of the contract section and the heavy materials required, a rail system is planned to supply tunnelling operations. There will be two tracks in order to avoid delay, which could affect the supply of the TBM with a single-track system due to the necessary time-wasting passing sections. Most of the supply to the mechanical tunnel drive will be from the construction facilities area at the west portal. The excavated material will be transported away on a conveyor system. The conveyor belt makes use of the entire cross-section of the running tunnel bore and relieves the rail operation. The choice of a conveyor system was down to economic advantages and the continuous conveying overlong transport routes.

Conversion station
After excavation of the Lavanttal fault zone and entering the crystalline bedrock, the tunnel boring machine with earth pressure components is converted to hard rock mode in the previously constructed conversion station. The location of the conversion station was decided according to the criteria of sufficient stability of the rock, relatively favourable system behaviour with moderate displacements, and to ensure the necessary bedding for the segments. The EPB components, such as the screw conveyor and the compressed airlock, will be dismantled in the conversion station, as no active face support will be needed in the section through stable crystalline. Modifications, such as upgrading the cutting wheel (strengthening) and converting the grouting of the annular gap with mortar to pea gravel stowing, consider the specific geological and geotechnical conditions of the crystalline section, including higher rock strength and increased deformation potential of the rock mass.

4. Equipment of the TBM at KAT 3

Drainage drillings
Although the stretches excavated for the investigation tunnel are expected to provide a drainage effect in the north bore, it cannot be ruled out, particularly in the transitions between more solid and looser strata, that groundwater aquifers could be encountered

during tunnelling and have to be overcome. The machinery must offer three possibilities for relieving groundwater pressure. For the stretches not excavated for the investigation tunnel, measures are to be provided to relieve groundwater pressure from the machine. Preventer equipment is to be available in case of higher water pressure.

<u>Mass balance system</u>
In order to record overcutting with certainty, redundant weighing systems, for example belt weighers and optical volume controls, are to be provided with a precision of at least ± 5%.

In the stretches with the character of soil (neogenic), the annular gap will be completely pressure-grouted through injection pipes (lisenes) integrated round the shield tail. In the stretches through hard rock (crystalline), the segment ring will be bedded on a mortar bed injected through the lower injection pipes. The remainder of the annular gap will be stowed with pea gravel through openings in the segments as the segment ring leaves the shield tail. In both cases, the penetration of the filling material into the steering gap must be prevented in order to ensure adequate and sufficiently early bedding of the ring. This will require a shield tail seal, which is to be constructed as a redundant system, e.g. spring plate and greased steel brushes. To the inside of the tunnel, a tried and tested brush seal should be provided for sealing during mortar grouting. On account of the great length of the tunnel with the resulting wear, all systems must be constructed reversibly to exchangeable on site. Constant supervision of fitness for purpose is required during tunnelling.

In contrast the situation in the mostly stable rock of the crystalline, active support of the face is to be provided in the neogenic through the use of a shield machine with earth pressure components. The shield machine should be capable of operating in three modes according to the ground conditions encountered:

<u>Machine concept for the Tertiary section and the main Lavanttal fault zone</u>
Tunnelling class VK 1 (open mode with provision of compressed air)
The TBM is operated primarily in open mode in the silt/clay stone and sandstone ground types, which are hard rock designated as soft rock. The precondition for the selection of this operating mode is stable face conditions with little or no ground water ingress; the excavation boundary must preserve the profile. The excavation chamber is filled as far as necessary for the running of the machine and mucking by screw conveyor. The face is supported by the pressure of the cutting wheel to the face. If necessary, the excavation chamber is filled with compressed air to repel formation water inflows to a quantity that can be coped with by the construction method.

Tunnelling class VK 2 (transition mode)
Transition mode is used in all ground types in the Tertiary section if there is an increased potential for uncontrolled collapse of the face, especially under the adverse influence of (heavily running) groundwater inflows. The excavation chamber is to be filled to the point that excavation face support is provided by the excavated material in combination with the pressure of the cutting wheel, but at least as far as it is necessary for the compressed air to repel formation water.

Tunnelling class VK 3 (closed mode)
Closed mode is used to tunnel through the Tertiary section with strong inter bedding and embedded sand lenses and beds that are subject to pore water pressure and have low cohesion. These beds can also lead to siltation effects. Closed mode is also used in case of heavy formation water inflow and high water pressure with an inherent potential for rock falls and collapse at the face. The face receives active support from the conditioned earth slurry. The pressure bulkhead is designed to be pres-sure-tight. Muck is removed by the screw conveyor, which maintains a pressure differential to the material discharge. The support pressure is regulated through the thrust force of the thrust presses and the transport speed of the screw and is kept as constant as possible. Experience gained in the exploratory sections suggests that stable relationship conditions can be assumed at least in the short term, even in the low-cohesion ground types. Therefore longer stretches of the sedimentary section can be operated in open mode. However, it must be possible to switch to transition mode or closed mode at any time. When the conversion station is reached after

tunnelling through the Tertiary section and the main Lavanttal fault zone, the measures for converting the tunnel boring machine adjusted with earth pressure components to a TBM with shield, described above and illustrated in Figure 3, (including the conversion of the screw conveyor to convey or belt mucking) will be implemented.

Conditioning

For most of contract KAT 3, conditioning of the excavated material will not be necessary. Because however the necessity of processing the excavated material cannot be ruled out for some stretches, the machine must be constructed to make this possible. In case additives are used, the legal regulations regarding degradability and toxicity must be complied with. The conditioning is applied through foam lances, which are fitted through the bulkhead far into the excavation chamber. They must be placed as near as possible to the injection location in order to guarantee the best possible quality of foam. The foam recipe is to be adapted to suit the altering ground conditions and pressure in the excavation chamber in order to maintain constant quality. The quantity of foam injected is to be adapted to the advance rate.

Man locks

The excavation chamber of the shield machine is to be accessible for the pressurised operating mode, for inspection, in order to overcome blocks or concretions or to exchange tools. The residual groundwater in this case will be kept back by a compressed aircushion. A material and man-lock is to be provided consisting of at least two chambers for access to the excavation chamber, and this is to be de-signed for the pressure required for construction reasons. This measure is to be built into the machine and should enable the rapid overcoming of zones with major water ingress.

The hard rock section of the Koralm Tunnel in the section not already explored by the investigation tunnel is to be probed in advance by seismology. The results of this geophysical surveying will be checked whether they deliver sufficient information before the start of tunnelling. If the seismology is found to be insufficient, overlapping hammer drillings should be used to deliver advance information about geological conditions during the drive.

Rebuilding to TBM-S

After overcoming the Lavanttal main fault zone, the tunnel reaches the crystalline, which is the actual hard rock stretch under the Koralpe. The shield machine with earth pressure components will be rebuilt to a hard rock machine in an appropriate cavern. The following essential alterations will be made as part of the rebuilding of the shield machine to a shield machine type TBM (S):

- Removal of the equipment for active face support,
- Dismantling of the screw conveyor and replacement by mucking through the free area at the centre of the shield machine on a conveyor belt,
- Conversion of the annular gap grouting to annular gap stowing with pea gravel; the segment will be supported on a mortar bed in the invert,
- Modification and rebuilding of the cutter head to a hard rock cutter head.

The tunnelling machine is to be fitted as standard with the necessary equipment for the overcoming of tectonic fault sand squeezing rock formations. At faults, which were discovered in the course of the investigation tunnel, the plan is to stop the shield machine for maintenance work, if the rock is sufficiently stable. This planned tunnelling stop will be used for the following measures:

- Provision of the TBM with consumables like grease to reduce friction and bentonite,
- Drilling of holes protected by the preventer for advance drainage,
- Determination of the range of limit and alarm values for essential machine parameters like thrust force, revolution speed, penetration, power consumption, cutter-head, mortar grouting pressure, mass control of muck and stowing of the annular gap,

- Hammer drilling and rotary core drilling to investigate the geological conditions. To improve the rock properties and to prevent interruptions to tunnelling, the following measures are planned when required:
- Filling of smaller rock falls in the crown, e.g. with silicate foam grouting,
- Production of grout screens through the shield skin of the TBM,
- Rock stabilisation measures through high-pressure grouting in holes with packers or artificial resin grouting under high pressure,
- The possible withdrawal of the cutter head in order to keep the gap between cutter head and shield cutter small, e.g. to prevent the face breaking away in advance of the cutter head.

5. Progress of work

The ÖBB Infrastructure AG commissioned the Porr AG with the execution of works for the construction lot KAT 3 on 09.09.2013. It is planned, to start the construction works for the shield machine for the northern tube on 15.10.2015. The design process for the machine is largely complete in the end of February. The production of shield components in the factory is well advanced. The segment design planning is implemented. The segmental forms are in production.

The tunnelling work in the conventional driving section of the south tube is starting at the beginning of January 2014 as planned.

The use of the support measure corresponds to the planning. The construction work on Mitterpichling, where the tunnel is constructed in cut and cover, is according to the plan. The bottom of the tunnel was concreted in the end of February. The preparatory work for the shield start already recorded on February 2015. The shield is scheduled to start from an 80 m long launch tube. Logistic and static aspects in the form of extremely low overlay of soil were the main reasons for choosing such a starting concept like this. In the final state the cut and cover construction is overwhelmed, whereby the original ground shape can be recovered. Secondary the excavated material is used as waste material.

Overall, the project KAT 3 provides a highly sophisticated engineering challenge. The project success mainly dependent on team spirit of the participants, which transparency and an open trusting communication foresees determined.

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