TUNNEL “WIENERWALD”

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ABSTRACT

The paper provides an insight into the design and tender of the more than 13 km long “Wienerwald” railway tunnel in Austria. The project comprises a double track tunnel section including an enlarged widening section at the transition to the two single track tunnels, a ventilation cavern with a permanent ventilation shaft, three permanent emergency exits within the double track section and more than 20 cross passages connecting the single track tubes. Temporary structures include an inclined disposal gallery and three shafts for ventilation during construction. For the disposal of excavation material not required for the construction of the open track a capacious landfill site is foreseen.

The project has been tendered with two design alternatives regarding the construction method applied for the single-track tubes at the western section of the project (conventional method NATM or TBM driving). For evaluation of the preferred bid a risk assessment was carried out to quantify the influence of the applied construction method. Finally three construction lots have been combined into one big tender package.

Molasse and Flysch formations characterize the geological conditions along the tunnel. The tunnel will cross several extensive fault/shear zones with an extension of up to 80 m. The overburden ranges from about 10 m at the portal areas up to a maximum of 200 meters.

Keywords: *railway tunnel (single/double track), ventilation cavern, tender alternatives, risk assessment*

INTRODUCTION

To increase the capacity of the westbound railway trunk line (“Westbahn“) is an essential concern both at the Austrian and the European level. To upgrade the line for four-track operation, a new 42 km double-track line is currently being built in the Vienna – St.Pölten section in addition to the existing line.

The first section of this newly built line includes the tunnel “Wienerwald” cutting through the northern mountain range called “Wienerwald”, a hilly landscape consisting of Flysch and Molasse formation. The tunnel, extending over a total length of approx. 13.3 km, has been designed as an extension of the „Lainzer Tunnel“ towards the West and is the largest and technically most challenging tunnel project tendered in Austria up to now.

The project comprises two single-track tunnels, each about 10.9 km long, a 2.2 km long double-track section with a 400 m long, stepwise enlarging cross sections and a pillar gallery at the transition to the twin single-track tubes. For safety reasons in case of an fire emergency a ventilation cavern with a permanent ventilation shaft, three permanent emergency exits in the double track section and 22 cross passages with a regular spacing of 500 m connecting the single-track tubes will be built.

Temporary structures include three vertical shafts with cross passages between the tunnel tubes for ventilation during construction, a steeply inclined mucking gallery to the disposal area equipped with conveyor belts and an inclined access tunnel in case of applying a conventional excavation method in the western section of the project.

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Client of the project is the Austrian Federal railway "OEBB-infrastructure construction agency" (ÖBB Infrastruktur Bau AG). The design was awarded to a joint venture of iC consulenten from Austria, Basler&Hofmann and Electrowatt Infra both from Switzerland, and Dr. Strobl from Austria. Lead designer is iC consulenten.

OBJECT STRUCTURE

For the tender of the project three construction lots have been combined (Lot LT26, Lot WT2 and Lot TF3) into one bidding contract.

Lot LT26 – "Lainzer Tunnel"

Lot LT26, which is the most western part of the "Lainzer Tunnel" is situated at the eastern boundary of the project area. Tunnel construction starts out of an already existing cut&cover structure and extends over a length of about 1.8 km as double track tunnel in western direction. Apart from the double track tunnel in this section niches and small caverns for technical equipment are foreseen. Due to safety reasons, three emergency exits consisting of vertical shafts and access galleries are also provided in this construction lot.

Lot WT2 – "Wienerwald Tunnel"

This section comprises app. 110 m of double track tunnel extending from the precedent construction lot LT26, which subsequently expands stepwise into a telescopic widening section over about 400 m in length. At the end of this widening a pillar gallery with a length of 40 m has to be foreseen. The pillar gallery is filled with concrete prior to excavation of the single-track tubes.

The single-track tubes run almost parallel with a track distance of 31 m over a length of approx. 10.9 km towards the western portal. At the portal a cut&cover tunnel and portal structures of app. 250 m length represent the final section of the tunnel.

The two single-track tunnel tubes are connected by cross passages with a spacing of 500 m. An emergency ventilation system (cavern and vertical shaft) will be installed app. 100 m west of the end of the widening section at the transition from double- to single-track tubes.

Excavated material, which will not be used or is not suitable for embankments west of the tunnel will be disposed at a landfill site in Taglesberg. Therefore a 400 m long steeply inclined, temporary disposal tunnel was designed.

Moreover, on the surface a water basin with a water supply line including a vertical shaft down to tunnel level is part of this construction lot.

To provide an additional possibility for tunnel heading in case of a conventional tunnel excavation an access tunnel from the area of the landfill site with a length of 1.2 km m was designed in the tender stage. Other temporary structures are three ventilation shafts including cross passages between the tunnel tubes.

Lot TF3 – "Tullnerfeld"

This construction lot consists of various earth-, road-, dewatering- and landscaping works (e.g. embankment for railway line, noise protection walls, infiltration ponds etc.) along the open railway line in westerly direction. The total length of this section is about 10 km.

Figure 1 shows a schematic layout of the construction lots LT26 and WT2 for the alternative with application of TBM.

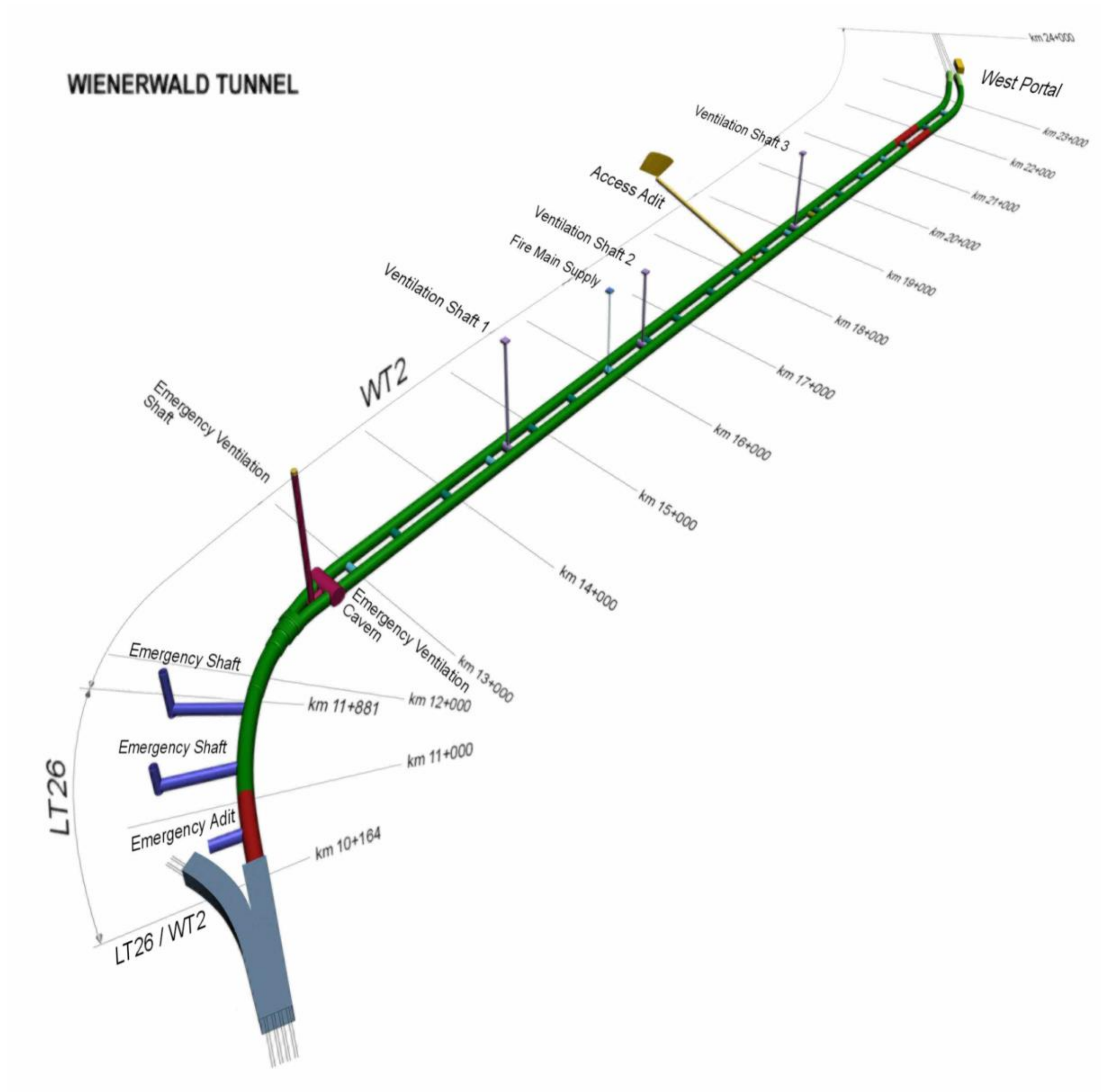

Figure 1: Schematic layout - construction lots WT2 and LT 26

GEOLOGICAL - GEOHYDROLOGICAL CONDITIONS

Geology

The major section of the tunnel (app. 11 km from East portal westwards) runs along a Flysch formation (heterogeneous rock mass) consisting mainly of shists and sandstone and mainly characterized by highly tectonised material. The most challenging situation for the tunnel excavation will be the crossing of some major tectonic fault zones. Fortunately the faults will be encountered in a very obtuse angle. Even so, one of the main faults ("Rehgraben Fault") has an extension of about 80 m and the tunnel passes under an overburden of nearly 200 m.

The western part of the tunnel is situated in a Molasse formation (poorly cemented tertiary clay or sand sediments), which underwent various tectonical deformations so that intense faulting and shear zones occur in this formation. At the transition between the Flysch and Molasse formation shear breccia and local insertions of Flysch material can be expected.

Hydro-geology

According to the topography in the Flysch section the groundwater level is situated in a depth between 2 m and 15 m below ground surface. Locally the depth below ground surface will be higher or artesian wells will be encountered.

Apart from joint water down to a depth of about 110 m minor water inflow can be expected locally in areas of sandstone or near shear zones. However in general no continuous groundwater layer exists. In greater depth joints of limited extension and filled with mountain water can be expected locally only.

In the Molasse formation the confined groundwater is situated in a depth of 1,5 m to 20 m below surface mainly in the sandstone layers and locally at the boundary between debris and Molasse. It is expected that within the Molasse formation a continuous ground water reservoir is present.

TENDER PROCEDURE

General

The project has been tendered in autumn 2003 with two design alternatives regarding the construction method applied in the western tunneling section of the project.

For the single-track tunnels between the western portal and the emergency ventilation cavern design drawings and tender documents have been prepared for using either tunnel boring machines (TBM`s) or applying conventional tunneling methods (NATM). All other tunnel structures of the western part and the double track tunnel of the eastern section of the project will be carried out by conventional tunneling method.

It was the first time in Austria that full sets of tender documents for two design alternatives have been provided by the client.

Risk Assessment

In order to be able to compare and evaluate the offers for the different construction methods a risk assessment for both design alternatives has been carried out. The risk assessment considered geotechnical conditions impairing tunnel stability or construction progress, possible damage to the tunnel lining, problems occurring with equipment during tunnel driving and impact on environment and surface structures.

For both construction methods following groups of risk parameters have been identified:

- Risks due to rock mass conditions for tunnel stability, excavation equipment, tunnel lining (e.g. rock pressure and tunnel deformation; occurrence of methane gas; abrasiveness of rock mass with high quartz content)

- Risks related to environmental aspects (e.g. surface settlements affecting buildings and infrastructure; effecting springs and wells; construction vibrations, noise and dust; train vibrations during operation)

For tunnel construction using a TBM following additional risk parameters have been examined:

- Getting stuck of the shielded machine in highly squeezing rock conditions

- Deformation of tail shield due to excessive rock pressure in major fault zones

- Risks related to equipment (e.g. failure of main bearing; fire hazard on the TBM; break-down of mucking system and interruption of material supply)

- Risks related to segmental tunnel lining (e.g. insufficient bedding of lining; increase of loads onto lining due to close spacing of parallel tubes; increase of loads onto lining due to excavation of cross passages)

Most of the risk parameters identified could either be eliminated during the tender design procedure, or considered in the bill of quantities or covered by provisions in the final contract documents.

Acceptable, potential remaining risks, which are allocated to the client´s responsibility and which could not be eliminated or fully covered by the tender design or the contract conditions were quantified for each construction method. The quantification was necessary to make both alternatives comparable in the tender evaluation in order to find the best bid.

The remaining risks quantified for conventional tunneling method were:

- Surface settlements in sections with low overburden affecting buildings and infrastructures
- Effecting springs and wells due to lowering of mountain water table
- Construction vibrations in sections with low overburden and hard rock conditions

In addition to the risks for conventional tunneling method following risks were quantified for using a TBM:

- Getting stuck in major fault zones
- Loosening of rock mass under shallow cover
- Instability of tunnel face, over-break in front or above cutter head
- Deformation of tail shield due to excessive rock pressure in major fault zones
- Insufficient bedding of segmental lining

Tender evaluation

For evaluating the best bid several other criteria beside the tender price were used. The so-called "modified offer" consists of the following factors:

- Tender price
- Increase or reduction of the offered price due to the offered construction period (factor A)
- Increase or reduction of the offered price considering the remaining risk acc. to the construction method (factor B)
- Additional costs for subsequent works (factor C)

Based on an average construction period estimated by the designer, factor A considers the increase or reduction on costs for the client for his services (e.g. project management, site supervision etc.) due to the bidders overall construction period.

Factor B accounts for the quantified remaining risks for each design alternative. For the TBM alternative also the technical data for the offered machine in comparison to specified values (see chapter TBM Requirements) have been included in this value.

Factor C takes into consideration different costs between the two alternatives, which will be incurred during subsequent construction works (e.g. for track works).

Finally, the best offer was the bid with the lowest "modified offer", provided the bidder meets all the other criteria and requirements (e.g. technical qualification, reference projects, annual turn over, financial requirements, etc.) specified in the tender documents.

Submission date for the construction tenders was end of February 2004. One out of four bidding groups submitted offers for both alternatives, the other groups submitted only the alternative with the application of TBM`s. Finally, the tunneling works for the TBM alternative have been awarded to a joint venture of the companies Porr of Austria and Bilfinger Berger of Germany in July 2004.

SELECTED DETAILS

Planned Construction Schedule

With respect to excavation method and heading direction the entire project has been divided into two sections:

<u>Section East</u>: East portal to emergency ventilation cavern (incl. cavern)

Tunneldriving in the eastern section commences from the cut&cover structure and leads along the double track tunnel (see Picture 1), the widening section including the pillar gallery and 100 m of single track tunnels to the ventilation cavern, which is also included in this section. Other structures of the eastern section are three emergency exits and the ventilation shaft. All tunnel structures are foreseen to be excavated by conventional tunneling method (NATM). Installation of the inner lining starting from the East portal will reach till the end of the widening section at the transition to the single-track tubes.

Picture 1: Excavation East portal - Lot LT26 (sidewall galleries)

<u>Section West</u>: West portal to emergency ventilation cavern

The single-track tunnels will be driven by two TBM’s, whereas the cross passages and the inclined muck disposal gallery will be excavated by NATM method. Tunnel excavation in the West with TBM’s starts after completion of the launch tunnels of 20 m length each with a 3 to maximum 6 month time-lag between the two tubes (see Picture 2). Depending on the working process dismantling of the TBM’s is either foreseen to take place in the ventilation cavern or in the running tunnels just in front of the cavern. Works at the disposal area and gallery will start in time so that after passing of the running tunnels the excavated material can be transported onto the disposal area as soon as possible. To guarantee smooth working operations three cross passages will be used for construction purposes. All concrete works for the single-track tunnels till the widening section, the cavern and the cross passages will start from the Western portal.

Excavation in the section East started in November 2004 and commencement of the works in the western section was in March 2005. TBM-driving will start middle of September 2005. After finishing the excavation works in autumn 2007 the construction of the inner lining is scheduled to last till summer 2009. The beginning of the final operation after installation of track system, safety systems, etc. is due to take place in the year 2012.

Picture 2: First Launch Tunnel West portal - Lot WT2

TBM Requirements

To reduce any remaining risks and to guarantee the comparability of the offered TBM`s during tender evaluation several minimum requirements were specified for the machines in the tender documents, such as:

- Minimum torque of cutter head (for the range of 0 – 2 r/min)
- Minimum torque of cutter head for start up (for at least 60 sec)
- Minimum total thrust per meter of shield length
- Minimum design load (rock pressure) for tail shield
- Minimum range of over excavation

The nominal bore-diameter was specified with 10,63 m including all tolerances for TBM-driving and placing of the inner concrete lining. Two of the bidders offered single shield machines, the other two double shield machines. Finally two single shield machines will be applied.

To overcome difficult areas such as fault zones several additional measures were specified for the TBM. Apart from common measures as over-excavation by adjustable disk cutters and conditioning of the material in front of the cutter head the machine has to be designed to enable the installation of an inclined pipe roof umbrella and inclined rock dowels through the shield as close as possible to the cutter head (3,5 m for the rock dowels).

Tunnel Lining

Apart from a section at the beginning of the double track tunnel in the East, where over a length of app. 390 m a watertight, reinforced inner lining is foreseen a drained final lining will be applied. No reinforcement is foreseen for most of the drained inner lining, except at intersections with niches, emergency galleries, cross passages, in areas with shallow overburden or squeezing ground conditions.

In order to keep vibration and noise emissions below acceptable limits for sections underneath buildings the installation of a mass-spring-system as track bed is foreseen. The minimum thickness of the inner lining for application of a mass-spring-system is 50 cm, whereat for the other sections this value reduces to 30 cm for tunnels excavated by conventional methods. For the TBM section the minimum thickness of the inner lining is 35 cm. The block length for the watertight lining is limited to 10 m and to 12 m for the drained lining.

The decision to apply a double shell lining for the TBM section has been made by the designer and client on basis of a risk analysis and cost comparison. The analysis showed clearly that a double shell lining consisting of prefabricated concrete segments with “open joints”, a waterproofing system and an in-situ inner lining is the best solution.

The waterproofing system consists of a waterproofing membrane, a protective layer and smoothening shotcrete. According to the clients requirements a watertight, reinforced invert slab has to be applied. To ensure a closed system the waterproofing membrane will be welded on joint sealing tapes embedded in the lateral faces of the invert slab. The sealing of block joints will be enforced by additional 50 cm stripes of waterproofing membrane in the roof/sidewalls and an additional outer joint sealing tape in the invert. Mountain water will be drained off by drainage pipes, which are placed laterally on the abutments below invert slab level.

The following Figures 2 and 3 show the regular cross sections for the double and single-track tunnels for the application of a mass-spring or slab-track system.

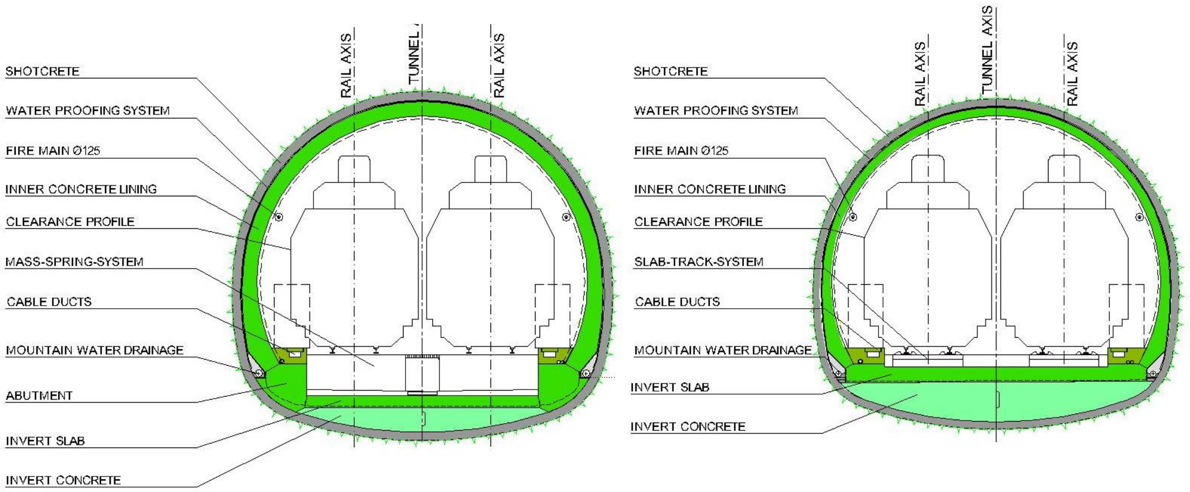

Figure 2: Regular tunnel profile for double track tunnel

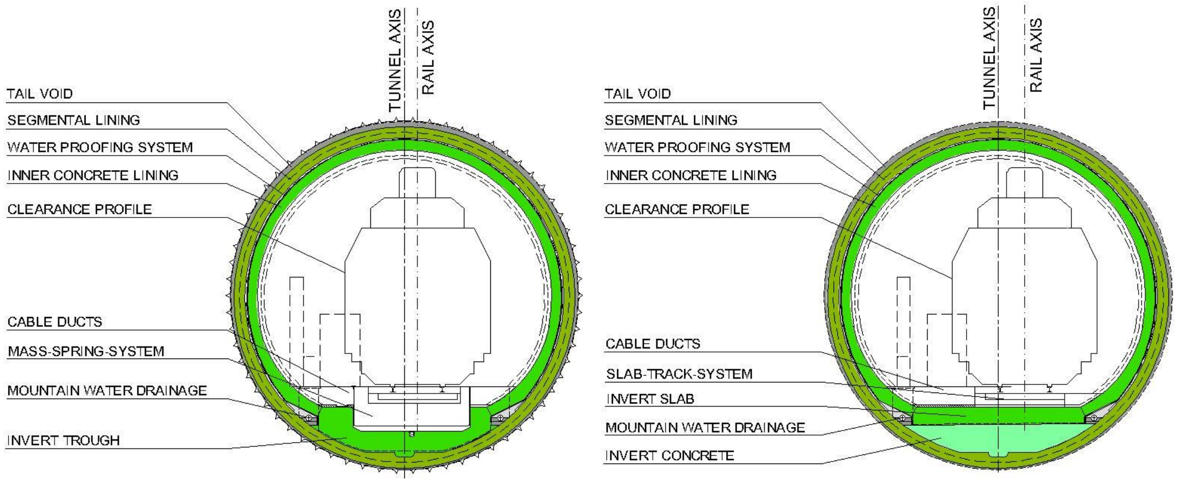

Figure 3: Regular tunnel profile for single track TBM-tunnel

Widening Section (Transition Double Track to Single Track Tunnel)

The 400 m long widening section for the transition of the double track tunnel into two single-track tubes is subdivided into four parts, which are widening stepwise, whereat the areas of the cross sections range between 130 m² and 250 m².

The excavation geometry for the first two sections of the widening is divided into top heading, bench and invert. The two biggest sections of the enlargement will be divided into a sidewall gallery and a residual part, which both will be excavated in a top heading, bench and invert sequence. The support measures for the maximum excavation profile include 40 cm of shotcrete reinforced with two layers of wire mesh, lattice girder, rock bolts up to 12 m length and systematic forepoling. Face support consists of shotcrete, wiremesh and face bolting.

The final inner lining will be a drained cast in situ concrete shell with a maximum thickness of 50 cm.

Due to the limited spacing of the two single-track tunnels at the end of the cavern a pillar gallery of app. 40 m length and an excavation area of 65 m² has to be executed first. The cast in situ concrete pillar, with a height of app. 8,5 m and a maximum width of up to 5 m acts as an abutment for the shotcrete lining of the subsequently excavated single-track tunnel tubes.

Figure 4 shows the maximum cross section and Figure 5 indices the two single-track tubes and the pillar gallery.

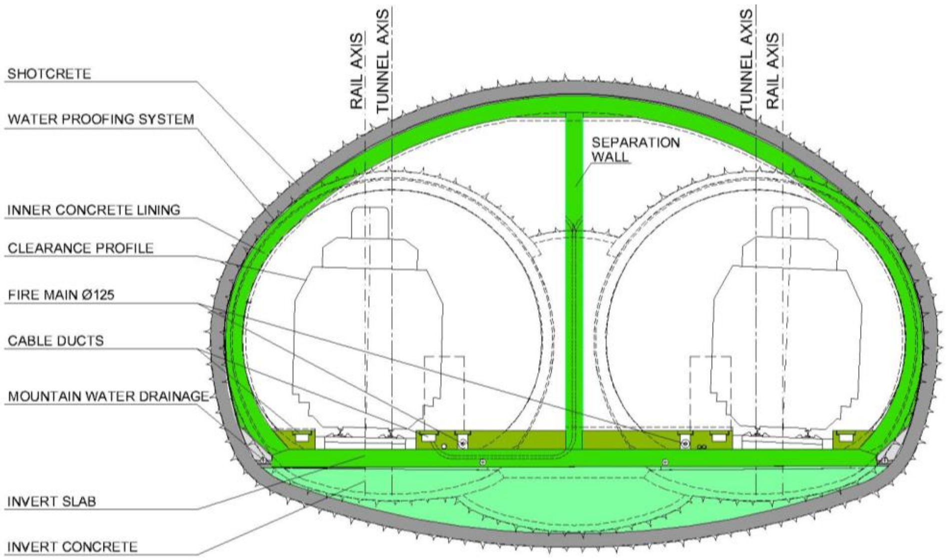

Figure 4: Maximum widening cross section

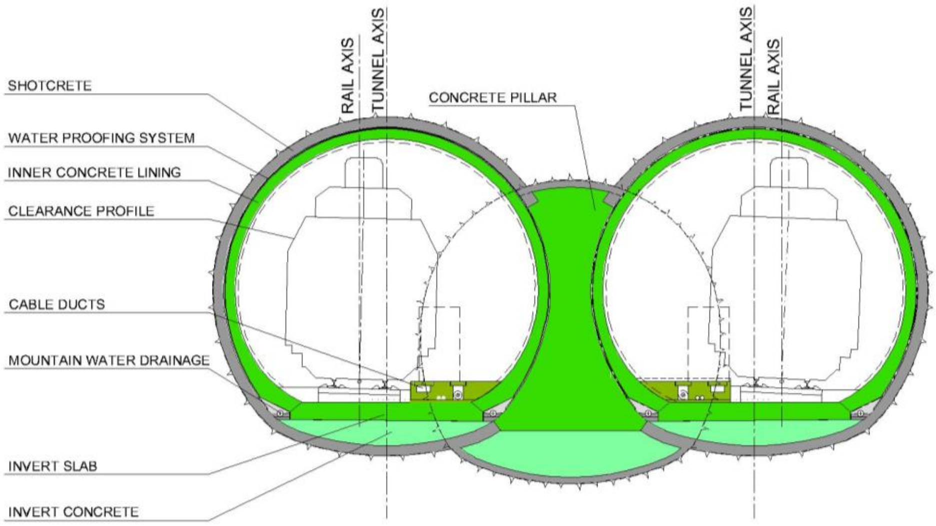

Figure 5: Single track tubes and pillar gallery

Emergency Ventilation Cavern

To prevent smoke propagation and therefore to keep one tube free of smoke in case of a fire accident in the parallel tube a ventilation system consisting of following structures were designed:

- Cavern for housing axial fans, transformer, electro-mechanical equipment
- Shaft including surface building
- Cross passage to connect cavern and shaft
- Cross passage to connect tunnel tubes at toe of ventilation shaft

The cavern is located at app. 100 m west of the end of the widening section perpendicular to the alignment. The spacing of the tunnel axes is about 20 m at this section. The maximum cross section of the cavern is app. 170 m² with a height of app. 15 m, a width of app. 18 m and a length of app. 35 m. The excavation profile of the cavern is subdivided into sidewall gallery and residual part. Finally a drained lining consisting of a waterproofing membrane and a reinforced concrete lining with a thickness of 40 cm is foreseen.

The shaft with a final diameter of 4,5m and a height of app. 200 m will be carried out by a pilot drilling, raise boring and conventional widening from top down. Finally a drained lining consisting of a waterproofing membrane and a generally unreinforced concrete lining with a thickness of 30 cm is foreseen. Only the abutments near the bottom of the shaft will be reinforced.

The cross passage to connect cavern and shaft will be carried out by conventional method and lined with a 20 to 30 cm reinforced secondary shotcrete lining.

The cross passage between the tunnel tubes, which will later act as emergency cross passage as well, will be driven by NATM method and lined with a drained concrete lining.

Figure 6 shows the longitudinal section of the cavern perpendicular to the single-track tunnels, whereat Figure 7 indicates a profile parallel to the tunnel axes.

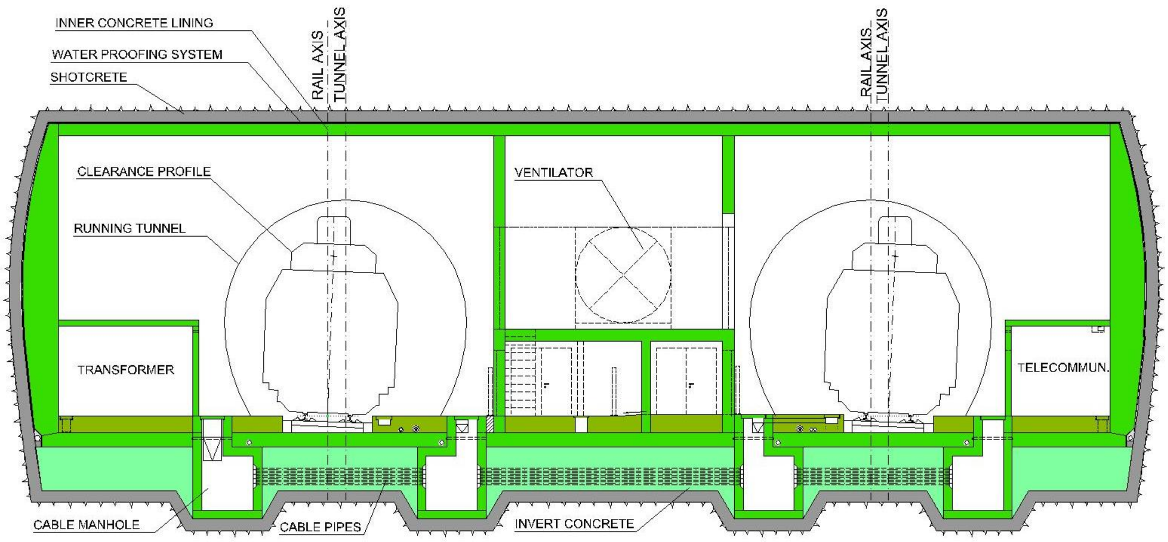

Figure 6: Emergency ventilation cavern – longitudinal section

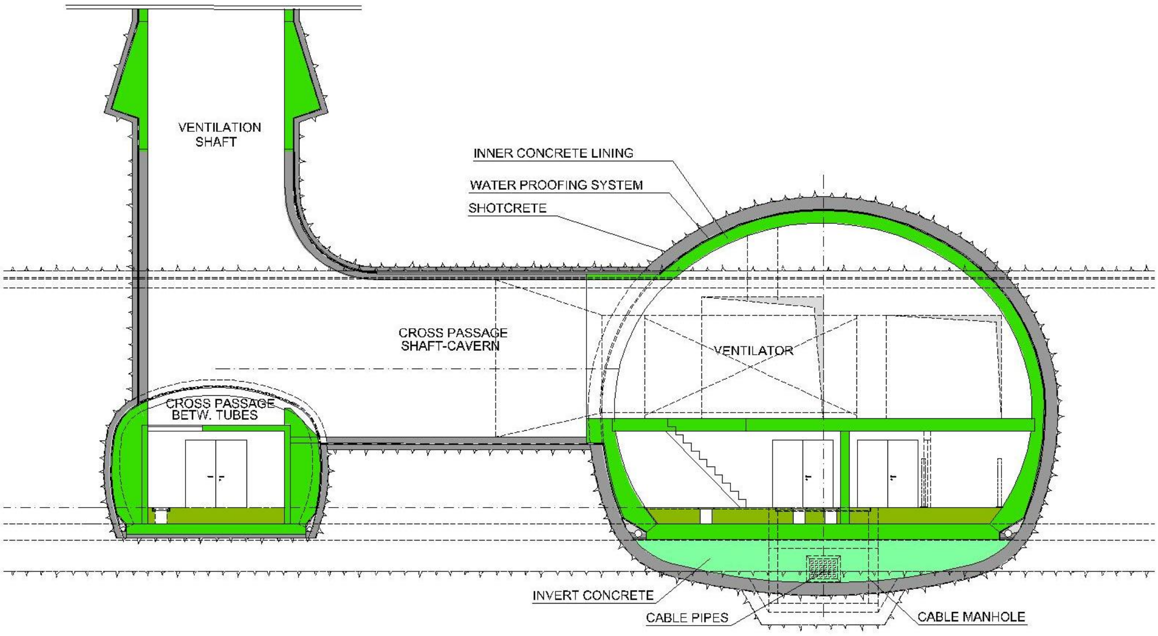

Figure 7: Emergency ventilation cavern – profile

Further Safety Facilities

Due to safety requirements two vertical emergency shafts and one horizontal emergency gallery are designed in the double-track section. The emergency exits are connected with the main tunnel via short connection galleries, which have to be equipped with an air lock of min. 12 m in length. The maximum height of the shafts with a cross section of 75 m² is about 65 m. The maximum length of the connection galleries is 75 m, whereas the maximum cross section is app. 25 m². Figure 8 shows a typical situation of an emergency shaft connected with the main tunnel by a connection gallery.

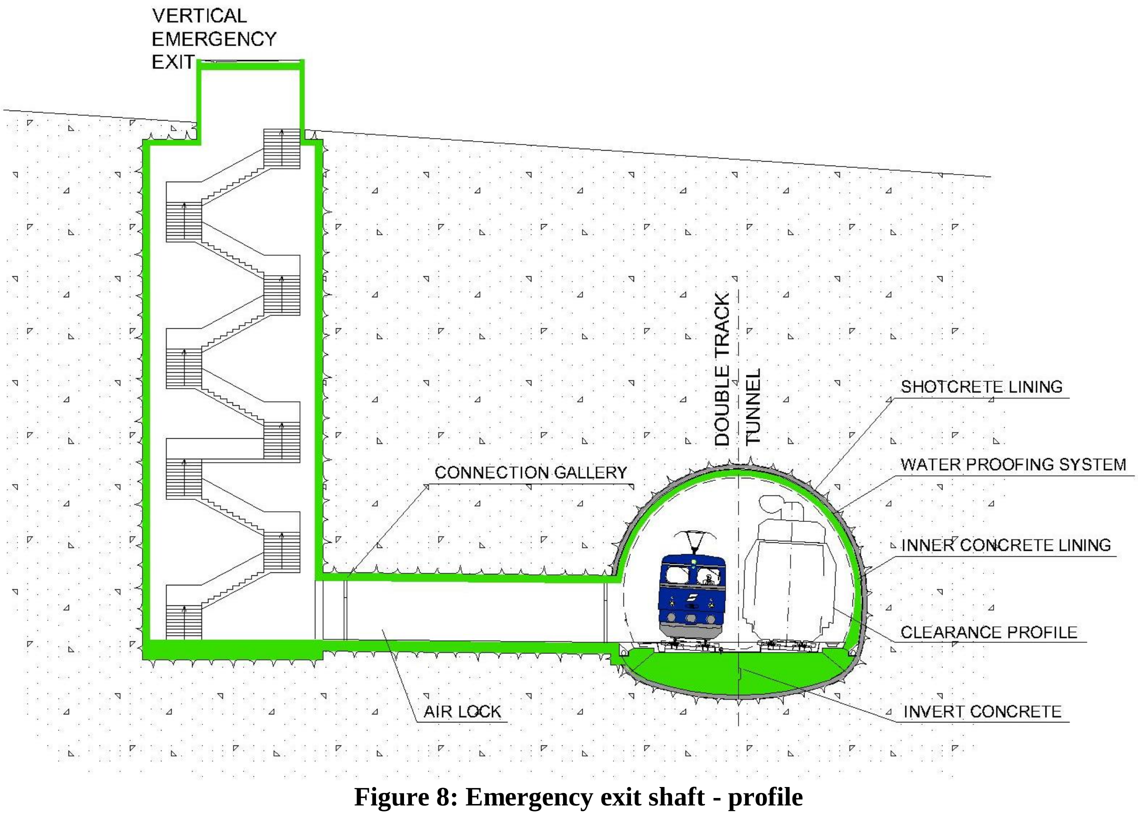

Figure 8: Emergency exit shaft - profile

The parallel single-track tunnels will be connected by cross passages with a cross section of app. 35 m² and a regular spacing of 500 m. They serve as emergency escape routes between the tubes and provide space for supply facilities. The cross passages must be closed at either side by doors to act as an air lock. The space between the doors must be at least 12 m long. Two ventilation fans installed in each cross passage keep the escape routes free of smoke in case of a tunnel fire. Figure 9 shows a longitudinal section and a layout of a cross passage connecting the two single-track tubes.

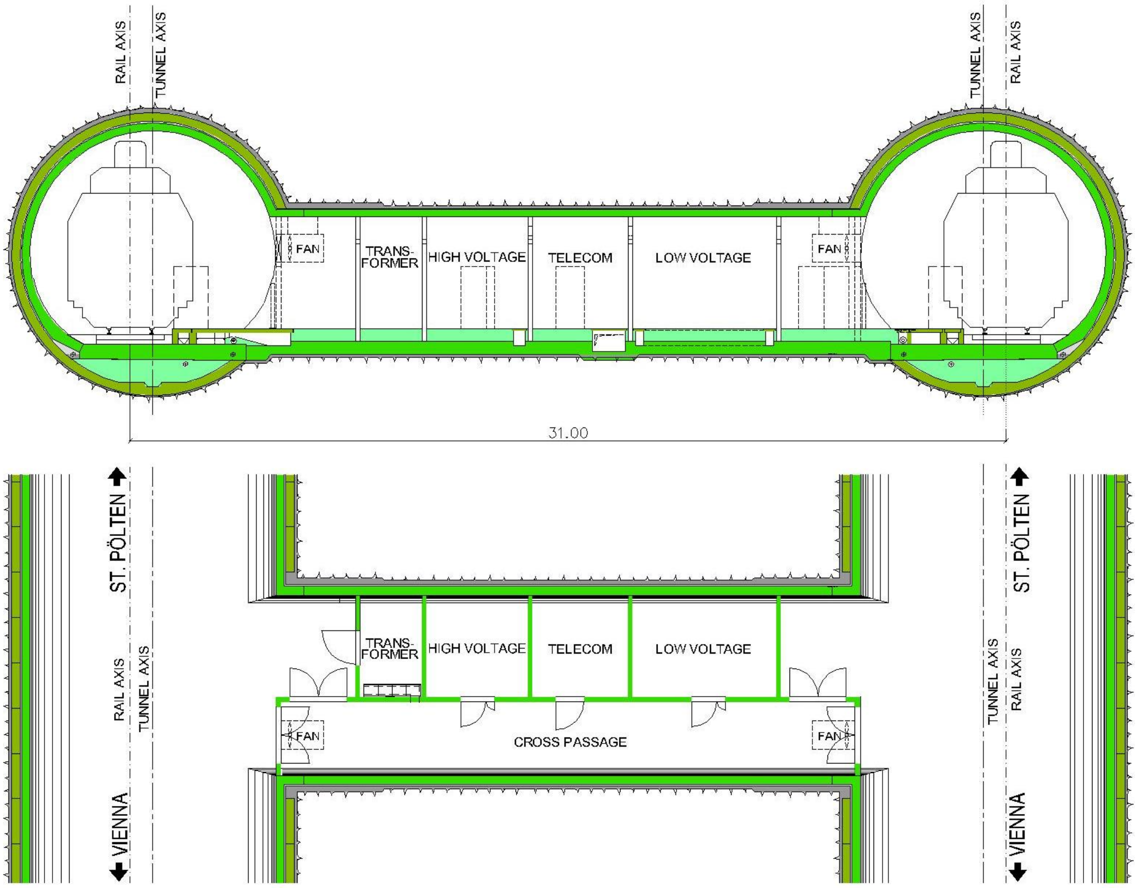

Figure 9: Cross passage - longitudinal section and layout

CONCLUSION

Long railway tunnels need careful design procedures through all design phases in order to get an economical project which fulfills all requirements with respect to environmental protection, safety of passengers, train operation and maintenance. The experience at the Wienerwald Tunnel Project showed that it is worthwhile to study carefully different suitable constructions methods and carry out risk assessment studies in order to get the most economic solution for the project. In case alternative construction methods are applicable tender documents considering these alternatives are to be favored, although the increase regarding design works can be significant. Design alternatives prepared by contractors during a rather short tender period are normally not in sufficient detail for a serious tender evaluation and a low risk contract award.

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