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Pilot project: applying the Tunnel-in-Tunnel method on DB electrified routes

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Abstract. This report deals with the refurbishing of the Petersberg Tunnel. In this connection, for the first time within the scope of the pilot project, the tunnel-in-tunnel method was applied on an electrified line belonging to the DB. The tunnel cross-section was enlarged within the scope of the excavation. These activities were executed with the aid of a tunnel enlargement system (TES). Towards this end, the existing overhead line for electrification of the route had to be integrated in the excavation. Once the driving operations had been completed, the tunnel inner shell made of reinforced concrete was produced. Thanks to this project the spectrum of refurbishing tunnels has been performed.

1 Deploying the Tunnel-in-Tunnel method for Deutsche Bahn

The tunnel-in-tunnel method has already been successfully tried out and further developed on several non-electrified routes in regional transportation. In this method, the tunnel cross-section is expanded by drill+blast or cutting tools with trains services still operating and a new reinforced concrete inner shell installed according to the valid requirements of the code of practice.

When construction starts, the track is relocated to the centre of the tunnel and services run in alternating directions for the duration of the scheme. Once refurbishing is over, the tunnel is once again provided with two running tracks. However, work on the track at the start and end of the tunnel enlargement scheme is undertaken during a scheduled complete closure phase; the route is kept open for traffic throughout the entire residual construction period. Traffic must only be occasionally rerouted if at all. The tunnel-in-tunnel method has now been deployed on an electrified route for the first time to refurbish the Petersberg Tunnel (Fig. 1).

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Fig. 1. The Petersberg rail tunnel will be refurbished by late 2019 by the tunnel-in tunnel method while rail services continue.

2 Project Presentation

2.1 Koblenz–Perl Rail Route

The Petersberg Tunnel lies near Bullay on the twin-track line from Koblenz to Perl, catering for mainline and commuter traffic. The route is of great significance for passenger transportation, linking Koblenz and Trier. It is also a vital artery for goods traffic as the most important link in the direction of Luxembourg. As a result, it rates very highly on the DB's route network. The DB Netz AG's long-term objective is to maintain the Koblenz–Perl rail line as an integral part of the Trans-European Network (TEN). Thus, enhancing the safety level as well as maintaining the route for goods and passenger traffic is of great public interest.

2.2 Petersberg Tunnel

The Petersberg Tunnel is 368 m long and was completed in 1879. The existing masonry consists of slate and quarry stone some 0.85 m thick. The thickness is reduced to around 0.70 m at the portals. The tunnel masonry structure is designed with a mouth-shaped cross-section; the tunnel is drained at present. The Petersberg Tunnel is located in the vicinity of the Moselle syncline, part of the Rhenish Uplands. The area consists of a thick geological sequence of sandstones, siltstones and mudstones. The rocks are in part intensively fissured and contain numerous faults due to the impact of tectonic activity. The maximum overburden height is to be found roughly at the tunnel centre and amounts to ca. 95 m.

The existing masonry of the tunnel has been redeveloped and improved on many occasions in the course of recent decades. During past maintenance operations, the masonry was provided with an extensive thin shotcrete shell. Prior to refurbishment, among other things, broken masonry, loose joints, spalling and cracks in the shotcrete as well as various moist

patches were documented. Within the scope of regular controls, it became evident that the quality of the structure was deteriorating, which could not be rectified economically. Furthermore, the Deutsche Bahn's valid code of practice calls for the track centre distance to be increased from its present 3.50 to 4.00 m. In addition, prior to renovation, there were merely individual emergency bays available rather than continuous escapeways.

The task of refurbishing the Petersberg Tunnel was carried out in conjunction with maintaining train services as far as possible even while enlarging the tunnel cross-section and installing a new tunnel inner shell. Minor interruptions were only permissible for blasting operations during the enlargement phase and for lifting and lowering structural parts above the overhead line. For this reason, the tunnel was enlarged by applying the tunnel-in-tunnel method. Construction activities began in 2017. The actual tunnel drive was commenced in January 2018 and wound up in October of the same year.

3 The Tunnel Enlargement System (TES)

3.1 Concept

Throughout the application of the Tunnel Enlargement System (TES) during construction operations, the running track was provided with a continuous protective housing [1, 2]. This was to ensure safe electrified train services and at the same time, separate rail traffic from ongoing construction. Within this protective housing, a conductor rail was installed in the roof to carry the overhead line. The overbreak for the additional housing was largely compensated for by deploying the conductor rail and the related low installation height of the overhead line system. The TES is a steel structure and runs within two guide rails, which are installed on the strip foundation, supporting itself above the protective housing (Fig. 2). The TES possesses an additional vault protective device that can be raised by hydraulic means [3]. By deploying this structure, the objective is to prevent the masonry of the existing tunnel from loosening. For other projects a bolting system was installed in the existing tunnel to secure it in advance.

However, this entailed a considerable amount of extra work, something that was avoided by introducing the hydraulically raised vault protection device for the Petersberg Tunnel. The TES had to be devised in such a way that it was possible to excavate using a drill hammer at the roof [4-5]. Two roadheaders, which moved along the tunnel base at abutment height, tackled the side walls (Figs. 3–5). The support arches and mats could be installed by means of mobile, foldable work platforms. Two shotcrete manipulators and drilling rigs located at the sides of the TES placed the shotcrete and created the drill holes for the anchoring system and the spiles. It must be observed here that the possibility of anchoring involving larger anchor diameters had to be taken into consideration when designing the anchor drilling rigs with regard to their effective capacity during the tendering stage [7-8].

The excavated material was removed by special dumpers behind the roadheaders, which had to operate in very constricted conditions. The protective housing as well as the TES was set up on strip foundations, running in the longitudinal direction of the tunnel. These strip foundations had to be capable of transferring the weight of the TES (approx. 225 t) and the housing safely into the subsurface. Owing to the local circumstances in the Petersberg Tunnel, driving was carried out by excavators and blasting (Figs. 6, 7). This meant that the TES had to sustain all effects from drilling and blasting.

Towards this end, the auxiliary foundations had also to be dimensioned accordingly. Fig. 8 shows schematically how the TES was impacted by the effects of blasting. Owing to the high horizontal loads (blasting pressure on the TES) the foundations had to be back-anchored using pretensioned GEWI bars. The work needed to accomplish this task took some

considerable time, leading to the construction cycle being interfered with [9]. Alternative concepts for sustaining this horizontal load should thus have been scrutinized properly in advance and resolved [10, 11].

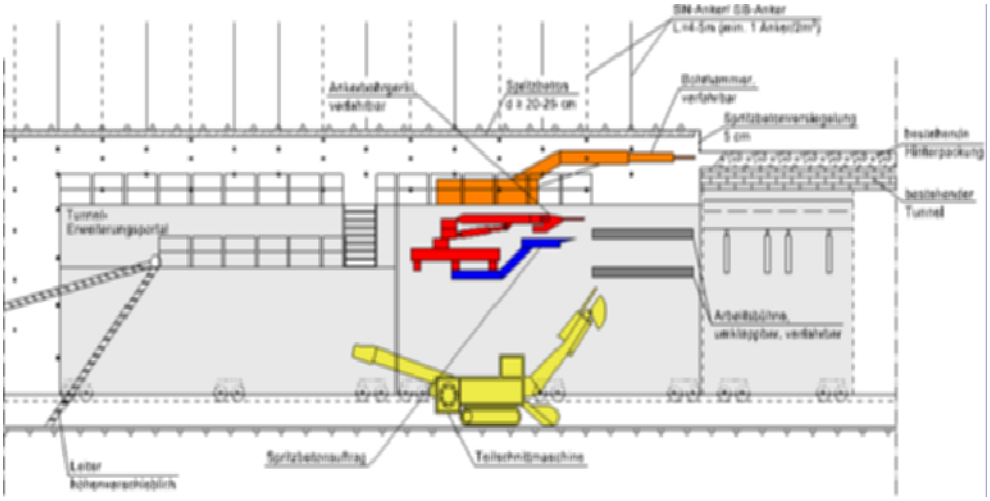

Fig. 2. Longitudinal section of the tunnel enlargement system (TES).

Fig. 3. Mobile TES installed on fixed housing.

Fig. 4. Mobile TES installed on fixed housing.

Fig. 5. Mobile TES installed on fixed housing.

Fig. 6. Excavation with a drill hammer.

Fig. 7. Drill+blast exavation.

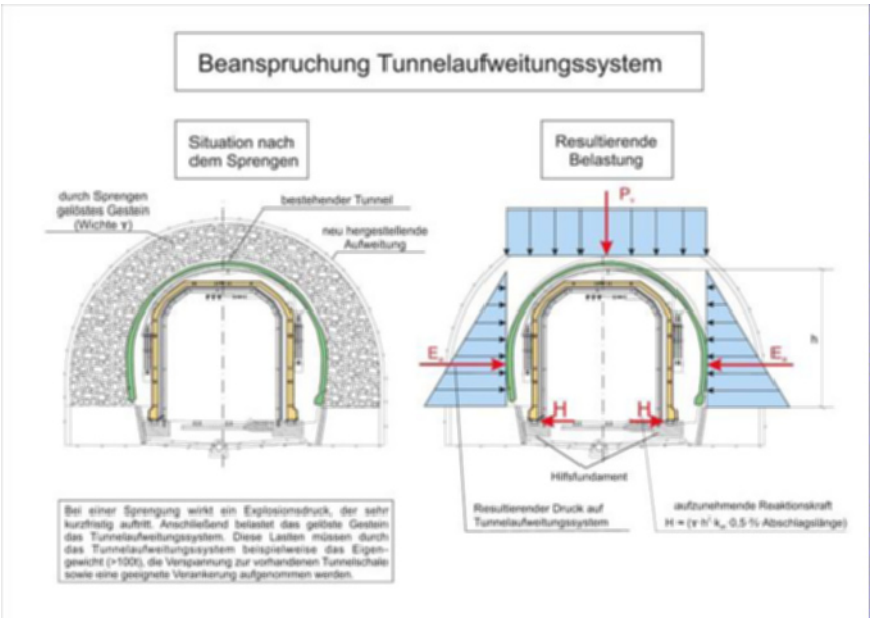

Fig. 8. TES impacted by blasting. During blasting explosion pressure acts which only lasts briefly. Subsequently, the loosened rock impacts the Tunnel Expansion System. These loads must be sustained by the TES, e.g. the dead weight (> 100 t), the bracing against the existing tunnel shell as well as by appropriate anchoring.

3.2 Construction Phases

Prior to the construction scheme, the route leading through the Petersberg Tunnel ran on two tracks. Within the scope of a four-week long closure of the route in May 2017, first of all the overhead line, the rails and the superstructure in the tunnel were removed. This was followed by the installation of the auxiliary foundations for the TES as well as the protective housing. In addition, the rail bed was produced with a track at its centre in order to enable rail traffic to pass through the tunnel in alternating operation during the entire construction phase. The protective housing was set up at the end of the shutdown. In August 2017, the TES was hoisted from the construction site installation yard next to the tunnel portal on to the auxiliary foundations during an additional night-time shutdown. In February 2018, driving operations began from the south portal. Towards this end, the tunnel was extended upwards by some 2.5 m (roof) and by roughly 3 m at the side (abutment zone) protected by the TES and subsequently secured with shotcrete (20–30 cm), anchors, support arches and matting. The lengths of advance varied between 0.75 and 1.75 m. The excavation over a distance of 330 m was concluded in October 2018. After the TES had been retrieved, the base was prepared for the foundations. Subsequently, the strip foundations had been created since January 2019. After setting up and positioning the reinforcement carriage, the formwork carriage and three curing carriages, work on the vault blocks started from north to south. Within the framework of a four-week long total closure since November 2019, among other things, the protective housing was removed and the auxiliary foundations dismantled prior to producing the rail ballast with two tracks. During the same period, the rail engineering, installation of the drainage pipes and the overhead line took place. After the shutdown, the tunnel will once again be ready for two-track operation. Fig. 9 shows the described construction phases.

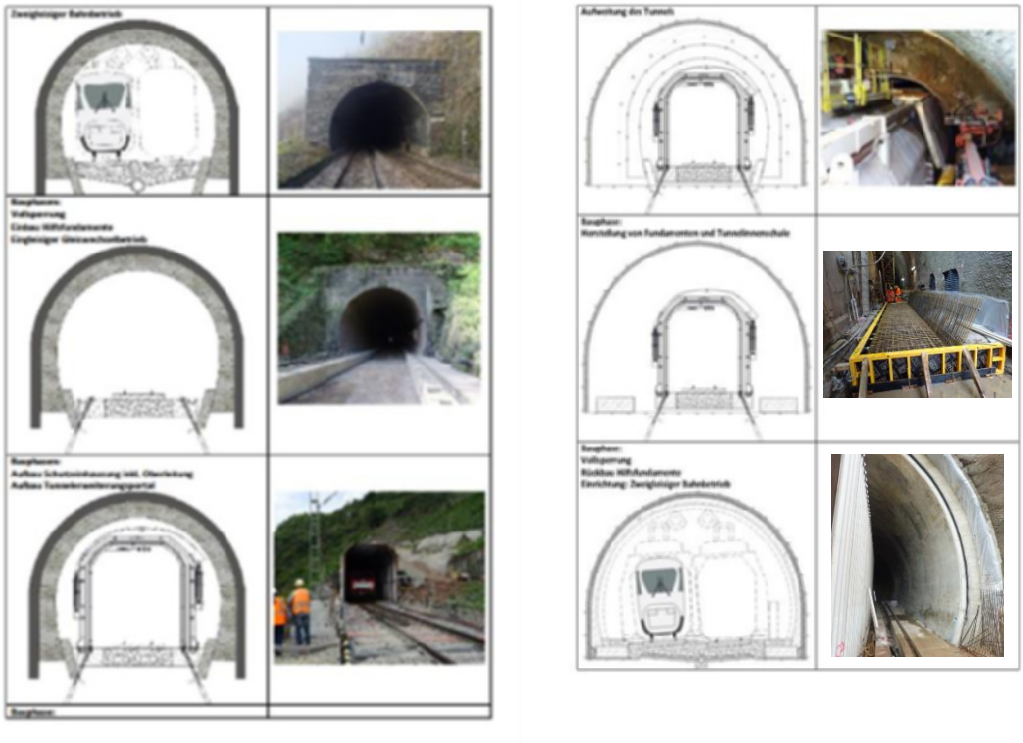

Fig. 9. Individual construction phases during the application of the tunnel-in-tunnel method.

4 Excavation Classes

The tunnel enlargement was undertaken commensurate with the principles of the shotcrete method. During planning, a total of six excavation classes (EC = VKL) were devised. Installation of the supporting agents essentially had to be carried out from the TES. This actually meant that the placing of shotcrete, drilling of anchors and spiles as well as the installation of matting and support arches in the entire excavation area had to be accomplished from the TES. The length of advance in the six excavation classes varied between 1.75 m (VKL 4A1) and 1.00 m (VKL 6A4). The thickness of the shotcrete ranged from 20–30 cm depending on the prevailing rock stresses. Q188 and Q257 mats were used to reinforce the shotcrete shell. These were always installed facing towards the rock and at the airside.

During the excavation, spiles were used at certain places as advance supports; they are some 3–5 m long and possess a diameter of 32 mm. The spiles were set up at ≤ 25 cm gaps. The working face was sealed at certain points with 3–5 cm thick supportive layers of shotcrete. Face anchors were also placed in definitive fault zones. SN bolts or self-drilling anchors (anchor length 4–5 m, supporting force ≥ 245 kN, anchor pattern: one anchor every 2 or 3 m²) were deployed for securing the shotcrete shell. Self-drilling anchors up to 10 m in length were foreseen for back-anchoring to minimize the growth of deformations. The support arches were devised as 3-bar lattice girders. The driving concept initially foresaw the vault (height of excavation up to approx. 8.56 m) being tunneled in advance. Subsequently the abutment (height of excavation approx. 1.00 m) was tackled once the intervening gap was sufficient (> 10 m).

The length of advance for the abutment amounted to twice the length for the vault. Once the first reference values had been accrued for this type of excavation, the method was optimized to such an extent that the vault could be tunneled at the same time as the abutment without the need for a staggered approach. The support arches were extended to the base of the abutment so that the loads imposed by the rock could be transferred immediately (Figs. 10, 11).

The loads imposed by the rock were monitored metrologically. A daily measurement at up to five points per measuring cross-section was undertaken in the immediate working face area. On account of the low rate of advance, the measuring interval was increased as from roughly 30 m behind the working face. The maximum distances of the measuring cross-sections at the portal zones were restricted to 5 m in each case; in the tunnel, the gap amounted to ≤ 10 m. The outer shell was calculated and dimensioned in keeping with the finite element method. The deformations for the shotcrete shell determined accordingly were listed as permissible displacement values for the individual excavation classes. In this connection, a warning value (2/3rds of the permissible value) was defined. It was agreed that if this warning value was reached, all involved parties were to be informed for a joint appraisal of the situation and to decide on how to proceed. It was observed that the deformations of the shotcrete shell determined in the FEM calculation were never actually attained during tunneling.

It should be noted here that for the calculation, a pre-reduction factor of the working face, i.e. a reduction of the E-module was applied. This pre-reduction value was set at 0.6. Two main reasons were provided for the reduction. Firstly, the tunnel was initially completed back in the late 1870s. At the time, a massive masonry shell backfilled in the roof and wall areas served as the supporting structure. It seemed probable that while building the tunnel, redistribution of the rock in conjunction with the formation of a protective zone around the tunnel cross-section took place. The tunnel enlargement by up to 3 m probably failed to change this state of tension existing in the rock to any major extent. Secondly, the geotechnical characteristic values for the rock had been so conservatively set that the determined deformations were influenced accordingly.

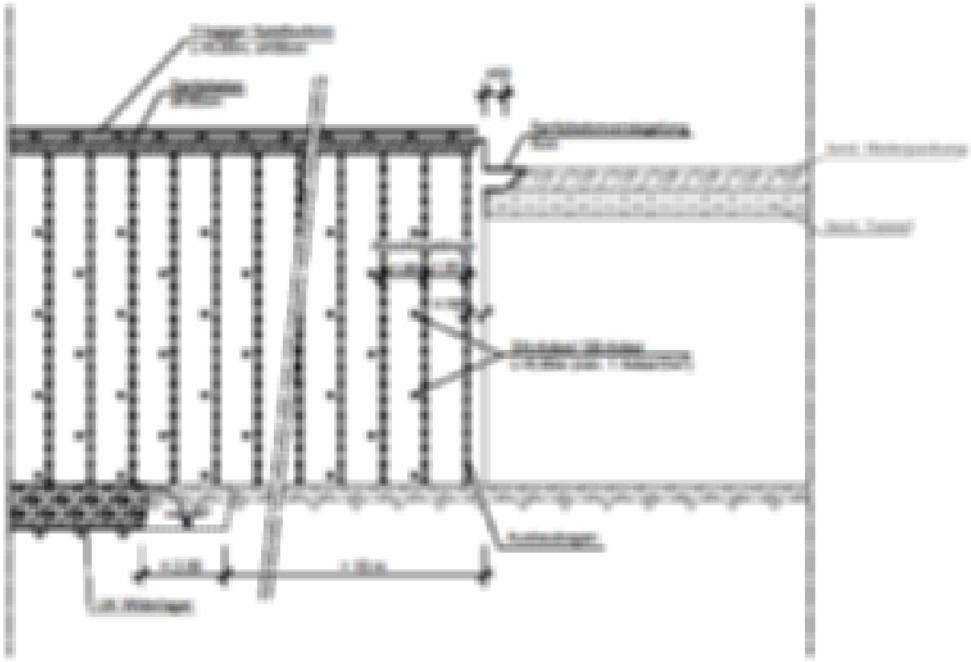

Fig. 10. Excavation class 6A4 (staggered excavation of vault and abutment).

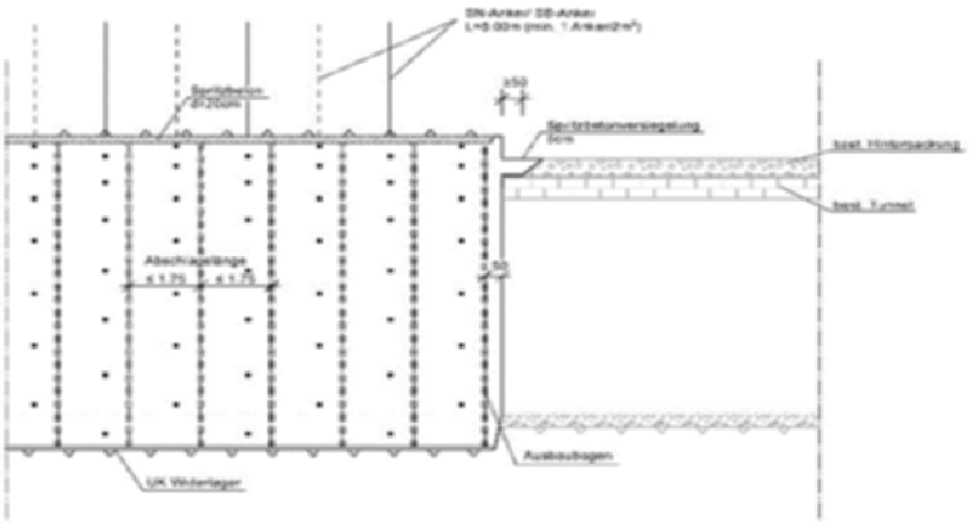

Fig. 11. Excavation class 4A1 (simultaneous excavation of vault and abutment).

5 Tunnel Inner Shell

Once tunneling had been completed, the reinforced concrete abutment was produced from the north portal. Then the tunnel inner shell was concreted, also using reinforced concrete. The inner shell was 40 cm thick and was produced from watertight concrete. The block joint comprised internal FMS 350 joint strips with central hose and steel lugs. The block length amounted to ≤ 10 m in each case.

A sliding layer was placed between the inner shell and the outer one. The tunnel was provided with lateral wall drainage and a longitudinal drainage system beneath the floor. After finishing the tunnel inner shell, it had to be furnished. Towards this end, the route had to be closed completely for a four-week period so that the protective housing together with the overhead line could be removed and the auxiliary foundations as well as the central temporary track could be dismantled prior to reinstalling the overhead line and the tracks including ballast for two-track train services.

6 Conclusions

This report deals with the refurbishing of the Petersberg Tunnel. In this connection, for the first time within the scope of a pilot project, the tunnel-in-tunnel method was applied on an electrified line belonging to the DB. Thanks to this project the spectrum of refurbishing tunnels has been considerably expanded, as the method can be deployed for other projects on the electrified route network.

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