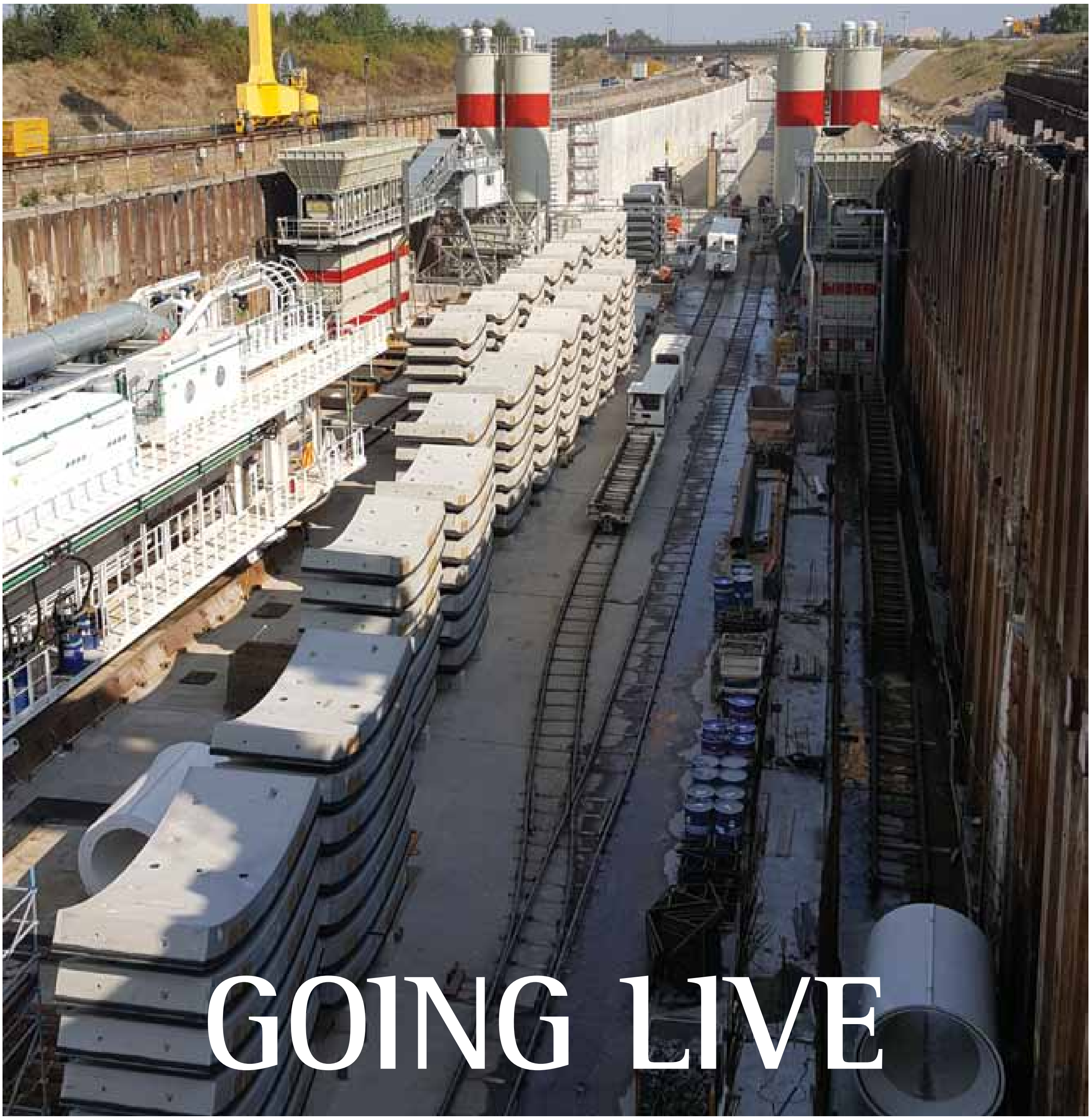


GOING LIVE

Tunnellers must advance through a ring of frozen ground protecting a live railway in order to build the Rastatt Tunnel and create vital new capacity along this crucial European transport corridor

Bernadette Ballantyne
Bernadette is a longstanding regular contributor to *Tunnels and Tunelling*

EXPANDING THE KARLSRUHE-BASEL rail corridor from two lines to four is a challenging proposition but as a key trans-European rail corridor it is a necessary one. The line forms part of the vital trade route from Rotterdam in The Netherlands down to Genoa in Italy and adding two new lines will allow separation of freight and passenger traffic offering significant benefits to both.

One of the most difficult sections of the project is construction of the Rastatt Tunnel where two, about 4km single bores are required to take the new rail lines beneath the Rhine Valley Railway and the Federbach conservation area. Not only is the ground saturated and soil conditions variable, the tunnel is relatively shallow with the overburden ranging from just 3m

Above: ***The TBMS are moving from north to south to create the two 4km-long tunnels***

to 19m. "We have all kinds of ground engineering methods like sheet pile walls and diaphragm walls, bored pile walls, jet grouting, micro-piles, underwater concrete and ground freezing," says Jörg Steppuhn, technical and contract manager for the Ed Züblin/Hochtief joint venture Tunnel Rastatt.

Among this selection of ground stabilisation solutions is an approach that has never been undertaken before, freezing the outer circumferences of the tunnel bores beneath the railway before ploughing through them with the two 10.97m diameter Herrenknecht Mixshield TBMs. "Crossing the Rheintalbahn [Rhine Valley Railway track] it is foreseen to have a ground freezing ring," says Martin Geiger, TBM manager for Züblin. "To produce it two shafts are located at either side of the tracks at a distance of approximately 200m and we have started to drill from that shaft 100m in either direction."

On site the team are in the process of driving the pipes that will later be frozen. "We are drilling the freeze pipes here," says Sören Henke, site manager for the ground freezing and other ground engineering works, pointing at the 30m-deep concrete shaft where a ring of 42 drill pipes are being pushed through the ground using horizontal directional drilling. Placed at approximately 950mm centres and 100m long, the pipes will freeze a 2m thick-band around the tunnel and most significantly ensure that the existing railway, which is only approximately 5m above the tunnel crown, is not affected by the passage of the machines. Crucially the railway line is not allowed to close at any time so prevention of settlement is the biggest priority. "It is the most important challenge for the whole project. The overburden is 4-5m and the railway must remain open," says Geiger.

In fact so cautious is the approach by project client Deutsche Bahn (DB) that as *Tunnels & Tunnelling* visited the site the HDD rigs were paused as additional monitoring equipment was installed to ensure that this method does not cause any unacceptable movement. "We are waiting to continue as we expect some influence on the tracks from the drilling so we are waiting for the railway to bring a tamping machine in to repair the track if needed. It's a precaution," says Geiger emphasising that there has been no damage to the tracks to date.

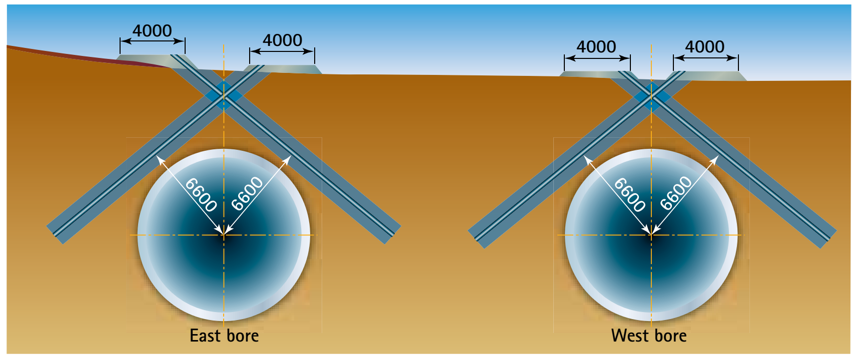
The decision to use the TBM for such a shallow section was a method recommended by the contractor. "Originally it was foreseen to stop the TBMs and do traditional tunnelling with excavators in the frozen ground but we suggested a technical innovation - to continue with the TBM through the ice, which saved money," says Steppuhn. This section, which is located at the very end of the tunnel bore to the south of the line, will then involve construction of cut and cover tunnel after the retrieval of the TBM, connecting to a trough section which is already under construction. Naturally a huge amount of work was undertaken to ensure that this technical innovation would be possible. Thermal and static investigations were conducted by the joint venture to examine the behaviour of the freeze zone. It is crucial that the frozen area remains watertight and that there is no thawing caused by release of thermal energy by the TBMs,

Vital statistics

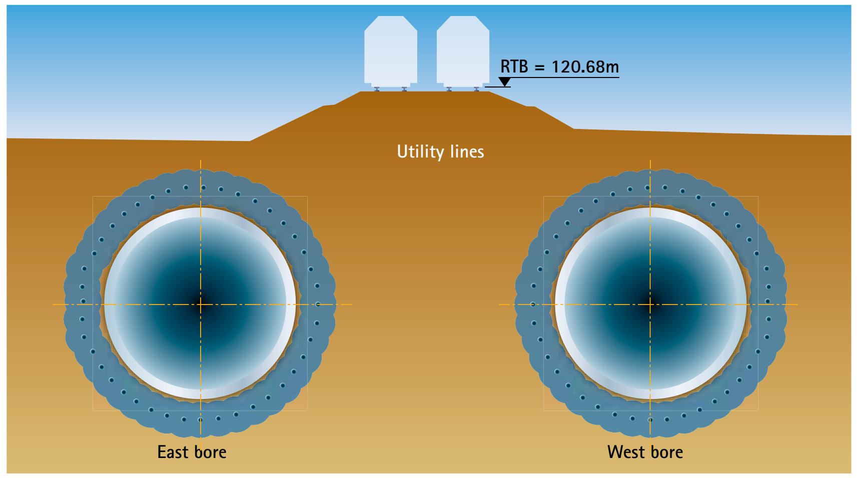
Tunnel bore: 3,890m + 4,030m
Diameter: 10.97m
Internal diameter: 9.6m
Excavation volume: 750,000 million cubic metres. (roughly 1.4M metric tons)
Concrete Trough and Cut and cover tunnels: north l = 800m / south l = 895m
People on site: more than 100
Contract value: EUR 312M (USD 330M) for the Ed Züblin AG/Hochtief Solutions AG joint venture Tunnel Rastatt.
TMB cost: EUR 36M (USD 38M)

GROUND FREEZING:
Federbach (roof): 22,000m³ (190 m + 290m)
Rheintalbahn undercrossing (ring): 27,600m³ (2 x 200 m)

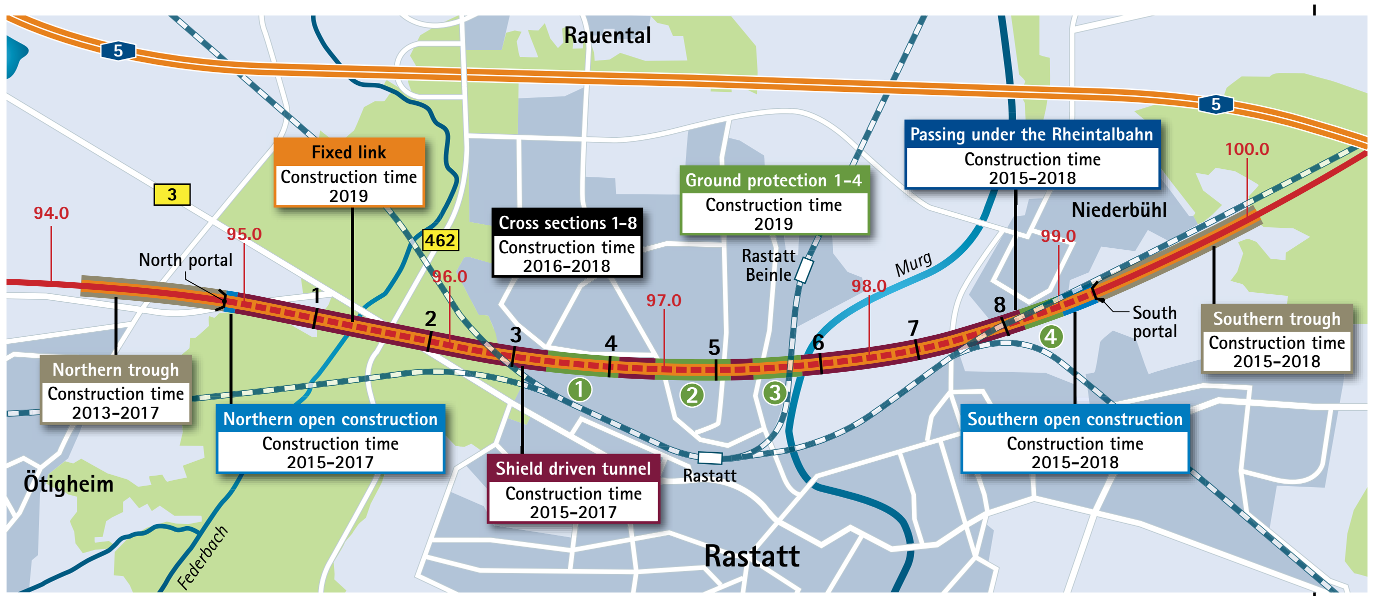
MATERIALS:
56,0000m³ of supporting walls of the construction pits/groundwater basins for the trough and cut&cover sections
123,000m³ of in-situ concrete,
33,000m³ of underwater concrete and
17,000t of reinforcement



*Below: **Figure 1, Freezing beneath Federbach. A total of 770 pipes use frozen brine to strengthen the ground and prevent blow out and protect the Federbach. The triangle shaped roof runs 190m above the east and 290m above the west section of the bore***



*Bottom: **Figure 2, Protecting the Rheintalbahn. The pipes will freeze a 2m thick band around the tunnel and ensure that the existing railway 5m above the tunnel crown, is not affected by the passage of the machines***



*Above: **Figure 3, Route map***

or just as importantly that the TBM does not itself become frozen as it passes through the ice. Engineers have devised a range of measures to ensure that this doesn't happen including reducing the amount of suspension in circulation and using aggregates that are less sensitive to temperature changes. "In the planning phase we even had considered a TBM standstill in the frozen ground to be on the safe side," says Markus Heimburger, the project manager for Herrenknecht.

The frozen rings are not the only area where cold temperatures are required to protect the ground. At the start of the tunnel to the north of the site, the cover is again very shallow at less than 5m. To prevent blow out and protect the Federbach conservation area a frozen roof structure was created above the tunnel using an array of 770 freeze pipes drilled, on average, 17m deep into the ground above the tube creating a triangle shaped roof along 190m above the east and 290m above the west section of the bore. "We cannot do a normal tunnel drive with the support pressure at the cutter head because we don't have enough ground above the tube, that means we have to use that construction to anchor the ground above the tube back to the deeper soil," explains Geiger. It also means that the cutterhead can

*Left: **Jörg Steppuhn, technical and contract manager for the tunnelling contractor the Ed Züblin AG/ Hochtief Solutions AG joint venture Tunnel Rastatt***

*Right: **Sören Henke, site manager for the ground freezing and other ground engineering works Ed Züblin AG/Hochtief Solutions AG joint venture Tunnel Rastatt***

Connecting the lines

Connecting Karlsruhe and Basel, the Rheintalbahn or Rhine Valley Line is 182 kilometres long and more than 150 years old. Critically important to rail transport, it is used for both regional and international connections. Today over 250 trains use the line daily and it has reached the limits of its capacity meaning that the original two-track line will be extended throughout to four tracks. "This will considerably increase its capacity and bring a substantial reduction in travel and transport times. The travel time between Karlsruhe and Basel will be reduced by half an hour to just 69 minutes," says Michael Bressmer, spokesperson for client Deutsche Bahn.

The overall project which includes the Rastatt Tunnel is made up of a total of nine line sections. For planning purposes these were divided into individual "planning approval sections" and these sections are all at different stages of completion and the first construction project for Achern Railway Station began in 1987. Previous tunnelling work on the scheme includes construction of the Katzenbergtunnel which was completed in December 2012 as part of the 17.6km long southern section of the works.

The upgraded Karlsruhe–Basel railway line sits at the core of the European goods corridor. The route between the Dutch harbours and the Mediterranean region is one of the so-called Trans-European Networks, arteries classified as especially important by the European Union. With leading-edge technology, these lines are meant to bring Europe closer together. In 2007 one of the most modern lines worldwide went into operation in the Netherlands, which is exclusively used for goods transport. This "Betuweroute" extends from Rotterdam to the German border.

The Karlsruhe–Basel line forms the northern feed to the AlpTransit, also known as the New Railway Link through the Alps (NRLA). This alpine transit route is to be especially efficient in order to create the necessary conditions to shift heavy-goods transport between Switzerland and Germany from road to rail.

The central projects of the NRLA are the Gotthard and the Lötschberg base tunnels. With a length of 34 kilometres, the Lötschberg base tunnel was opened back in June 2007. At 57 kilometres, the Gotthard base tunnel will be the longest railway tunnel in the world. The Gotthard line is continued to the south by the 16-kilometre Ceneri base tunnel, construction of which began in 2006.

Efficient operation also has to be guaranteed on the German side – this is one of the main reasons for the new and upgraded line from Karlsruhe to Basel.

only be inspected in this area by dropping the bentonite level by one-third the bore diameter of the TBM as the compressed air pressure used to replace the bentonite could otherwise lead to a blowout. So an inspection was carried out before the first machine reached the frozen roof.

This first TBM has undertaken more than 1km of tunnelling with the second about to get underway as *Tunnels & Tunnelling* visited the project. "Now we are deep enough for a normal tunnel drive without special construction at the surface," says Geiger.

Other ground freezing measures will be used to support construction of the eight cross passages and protect them from the potential for water ingress due to the high water level at the site. Located every 500m traditional SCL shotcrete lining methods are being used for these connecting tunnels.

But first the team must complete the main bore and below ground a seven-person team led by the contracting joint venture's project engineer Ursula Wegener, is making good progress in the quaternary gravels heading into the soft tertiary layer with quaternary rocks and cohesive covering layers of sandy clays and silts. The TBM operator is feeling his way forward at around 20mm/min applying 42,000kN of driving force at the face. Pumps are moving bentonite to the face at a flow rate of around 2500m^3/hour and each 2m advance takes around two hours. The Mixshield machine has a standard cutting head with an opening ratio of around 30 per cent. "It is all about getting the right balance," observes Wegener, with the multitude of control screens that tell her and the TBM operator everything about the machine and its relationship with the ground.

Below: ***Martin Geiger, TBM manager for Züblin***

Above: ***The contracting joint venture's project engineer Ursula Wegener***

One of the challenges that the underground team are facing is the abrasiveness of the ground which means that more inspections and more cutting tools have been required than was originally expected. "The abrasiveness of the ground is influencing the tunnel drive more than expected, we have been surprised at the amount of wear. When we are running we do 16-18m per day but we are having to change cutter tools more often which means standing still for two to four days and this brings the average down," says Geiger.

For Wegener the abrasive ground also means that her team must inspect the pumping equipment frequently to check for wear on the steel pipes. "Every week we inspect the slurry pipes and we can turn the pipes or place on extra steel if the wear is too much," says Wegener. Using electromagnetic measurement the team checks that the pipe thickness remains greater than 4mm as maintaining the slurry removal is clearly a critical activity.

Each tunnel ring consists of seven 11.5t segments which are manufactured in Bavaria by Max Bögl and transported by rail to Rastatt station before lorries transport two at a time to the site. The current delivery rate is three trains per week and 23 rings per train. "We are really pleased with the lining quality," notes Steppuhn.

Launching the second TBM was the next major task for the contractor as *Tunnels & Tunnelling* visited the site, which was planning to implement its bespoke flying shield start up method which has been used on Crossrail, and the Cologne and Hamburg metros.

"It means pulling the TBM forward instead of pushing it. The main principle of this kind of TBM launch is that the abutment for the TBM's driving jacks, unlike as the classic thrust frame, automatically advances towards the soft eye wall. This will be done by 24 hollow piston jacks and tension rods which connect the abutment with vertical steel girders at the soft eye wall. Those vertical steel girders then transfer the forces to a concrete beam above the portal and to the concrete slab," says Geiger.

The second TBM is purposely launched several months behind the first. As the bores are between 17 and 26m apart there is the potential for one bore to affect the other so a staggered start is required.

Unusually for the TBM manufacturer Herrenknecht, which delivers its machines all over the world, the project is conveniently close to their Schwanau headquarters. Development of the two 10.97m machines took around one year.

"For both sides it is an advantage the location being so close. It is easier to provide good and fast support for the job site, and we can bring people to see what we are doing. It is also an emotional thing for people at Herrenknecht – like having it in the family. People are proud of our TBM working so near," says Heimburger.

Despite the abrasive ground the team is maintaining good progress on the project and is well prepared for the challenge ahead, where the machines will bore through frozen earth just 5m below the existing live railway. Completion of the tunnel bore is scheduled for September with separate contracts for fit out, tracks and M&E works underway until December 2018 at which point the crucial link in Germany's Trans-European Network will be complete

Below: ***One of the project's rings***