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ALPINE FOCUS

Reports on tunnelling Austria's Brenner Pass and mucking out Zurich's railway

CONSUMABLES

T&TI reviews disc cutter developments as the technology approaches maturity

Cutting through Austria's Inn Valley

State of the art jet grouting, advanced slurry TBMs and high tech compressed air use have been among a slew of techniques used for the complex Inn Valley railway in Austria reports Adrian Greeman

For two year,s serious construction work has been underway on the exploratory tunnels for the Brenner Pass high speed rail project in Austria. Like the world record length 57km Gotthard Base Tunnel, now finishing excavation work in Switzerland, this will eventually be a very long deep-level base tunnel, in this case 55km, and up to 2000m under the high Alpine peaks.

To service this future link, a major programme of works is underway in Germany, Italy and Austria to build or upgrade a new European high-speed freight and passenger corridor, passing from Berlin and Leipzig through Munich and on into Italy to Naples and Palermo in Sicily.

A key early project is upgrading lines in the River Inn Valley, the centre of Austria's picturesque mountain Tirol. There are few choices for the route except to pass along the valley floor, just as the existing rail line does and the A12 motorway across the Brenner Pass.

But fitting new lines into the narrow valley is not easy. The flat lowland in the glacial U-shaped basin is at a premium for agriculture and dwellings, and there is also the river meandering through. Widening the existing twin track corridor to four lines is not

Above: The complex road, rail, stream and tunnel crossing at Stans

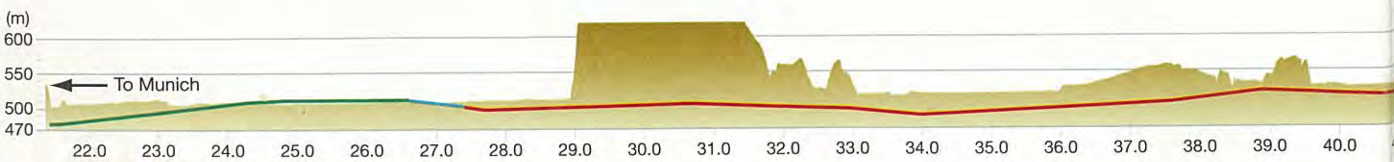
possible, as it would involve major realignment to accommodate gradients and curves for a 250km maximum speed track, and would increase noise and disruption in a popular tourist destination.

Shallow tunnels are the solution selected by Austrian Railways and the special Brenner Eisenbahn company (BEG) it set up to carry through the roughly €2.5bn (£2.3bn) project. Setting the new line just underground does not consume surface land, or impact the environment too much and bypasses valley bends by cutting through mountain outcrops. Some 32km of the 40km project, is bored or in cutting.

But that has meant complex challenges for the tunnellers, now largely completing the civil excavation work after six years of construction (T&TI September 2004) not least from geology. The valley floor comprises a deep layer of alluvial and mountain erosion debris fans, mixed up into 300m of heterogeneous sands, silts, loose gravels and sometimes cobble blocks. Its open structure is saturated by the river water with a table hovering 2-3m down and just 1m in the summer meltwater season. It means high water pressures at many points on the tunnel, up to 3 bar.

Settlement and disturbance is also a critical issue as the line criss-crosses under the motorway, old bridges, buildings and villages, and the existing railway.

Various techniques have been used to cope, in eight major construction contracts. Two long valley floor sections used Herrenknecht Hydroshields, and there is underwater excavation for cut and cover and assorted compressed air drives. There are also complex jet grouted ground arches and improvements. Most complex of all is a jet grouted tunnel "tube" in the ground at Stans excavated inside. There are also two major but conventional bored tunnels.



First section of the route begins in the lower part of the Inn Valley near the German border. For 5km the existing corridor is simply widened to four tracks, and then central high speed lines diverge and drop down a slope in an open cut before swinging out into a long tunnel section of over 13km split into a number of contracts.

First tunnel work tackles the 790m long cutting and a short entry section of cut and cover tunnel of just over 1600m. Though relatively straightforward, this €57M (£51M) contract, one of the last to start in April 2008, had its challenges, not least because of safety issues working close to the busy main line which carries over 350 trains daily. The contractor Strabag has constant communications with the operational teams.

The section was made within excavated steel pile trenches, the tunnel section, starting at 15m depth, being completed with a backfilled concrete arch made using a travelling formwork. Strabag used Doka formwork for the 12.5m lengths. The concrete is a watertight B300 specification sealed with resin injection at the joints and there is an additional PVC membrane around the outside "to be sure" says Martin Pellizzari, project spokesman from the BEG client.

In the alluvial ground the cut and cover excavations between sheet pile walls were inevitably water filled, and divers from local specialist firm Nautilus were a significant part of the operation. They guided the crane-mounted clamshell grabbing out of the usually 70m long compartments to ensure a smooth base in murky and often freezing water, and were crucial for work on a 1.6m thick underwater concrete slab which plugs the trench base before dewatering. Most all they were important for installing 15m long heavy ground anchors which help resist uplift, guiding the crane mounted drills over the water and fitting steel plate anchor connections.

Deepest dives were for a shaft on one of the safety rescue tunnels which are provided every 500m on the shallower sections of the tunnel. Shafts provide stairwells and access for small escape tunnels which link to the main tunnel.

Inside two long mountain drives on the project these shafts are replaced by cross passages driven from a second safety tunnel running alongside the main bore.

Just such a mountain drive takes the tunnel on for its next 4.2km on a curving route through a mountain bluff on the south side of the valley underneath the town of Brixlegg. Porr Tunnelbau and Germany's Bilfinger & Berger tackled the job with conventional drill and blast methods using Atlas Copco jumbo rigs and diesel trucks to muck out.

"We had an initial contract earlier for a 4.8m width service and investigation pilot tunnel which the main contractor could use as additional access, allowing him to open a total of five faces" says Pellizzari. "Blast rounds were typically 3.5m and support according to rock convergence." As with all the alignment, the initial lining, in this case shotcrete, is finished with an inner cast in situ concrete lining.

Two main issues confronted the tunnellers. First, although much of the rock is sound granite and limestone, there were sections of anhydrite, which expands on contact with moisture and required overcutting and then the use of a squeezable aggregate in the concrete lining to prevent cracking. The mix contained polystyrene balls to achieve the required compressibility.

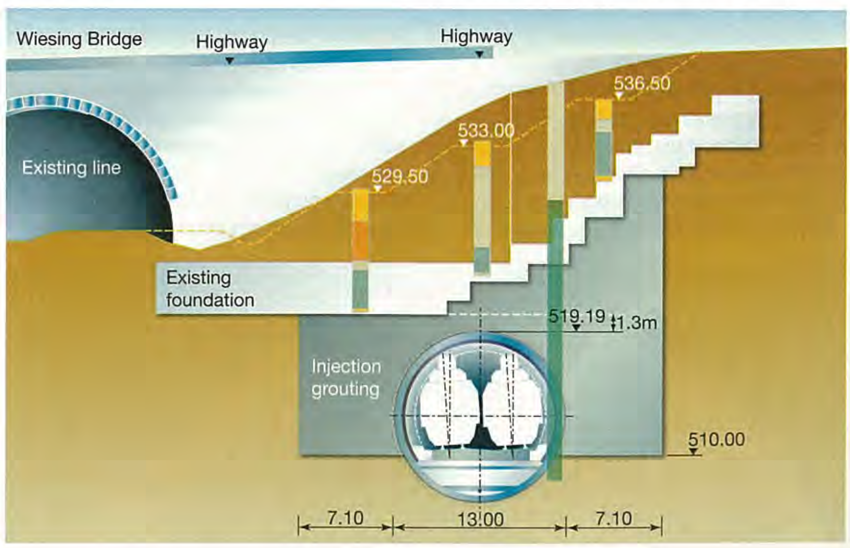
A more important issue was the presence of a mountain water table on around 1km of the drive, sitting up to 60m above the tunnel. To deal with this the section was drilled and dewatered before excavation, which was an issue because it feeds local springwater used for the community.

When the drive was complete and a watertight tunnel lining was in place capable of resisting up to 6 bar pressure, the dewatering stopped. But the springs did not return as expected. A trial and error detective task was needed to grout various drainage points in the tunnel before levels eventually began rising again.

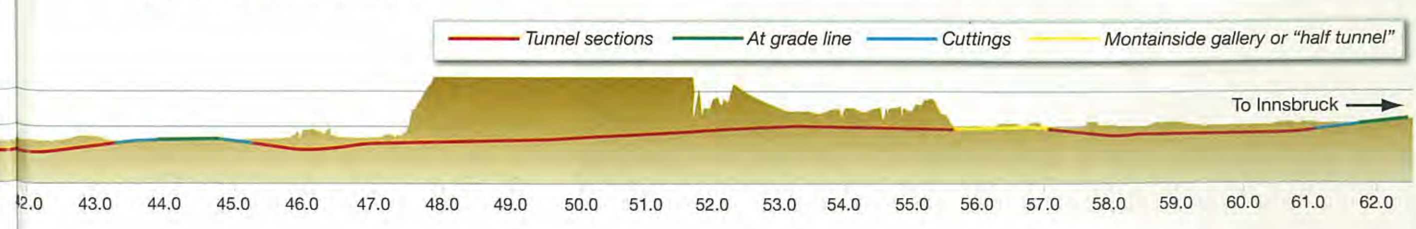
On other sections of the drive where the rock cover is much higher, and therefore potential water pressures higher, a drained tunnel design was used.

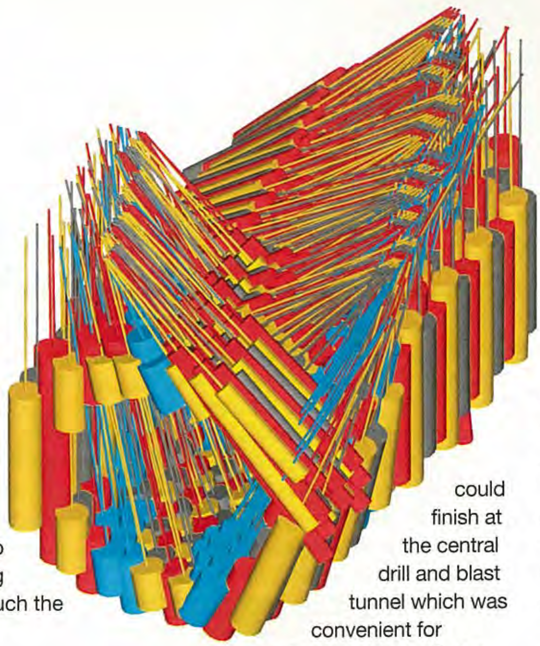
This rock tunnel leads into the one of the most potentially difficult sections, taking the tunnel alongside the river in the valley, and criss-crossing the river, the motorway and the rail line. For this work, in water column depths of up to 36m, pressures of up to 3.6bar were expected and it was decided to use sealed TBMs, the choice being slurry Hydroshields from Herrenknecht. Each was 13.03m in diameter, the largest used in Austria and close to the biggest anywhere in the world. Final internal tunnel diameter is 12.16m for the double high speed track.

The section divides naturally into two parts because a small mountain bluff



Right: Fig 1 - Jet grouting was required underneath the abutment at Wiesing bridge ahead of the TBM drive
Below: The tunnel in section





intrudes on the alignment just over halfway along, where a short drill and blast section has been carried out. Its 663m length left a drive of 5.8km to be made from the end of the Brixbegg tunnel on to the town of Wiesing and a second 3.5km drive onwards past Jenbach. The second contract also includes a section of cutting and grade level line where the rail emerges briefly to make a connection with the existing railway, but otherwise has pretty much the same challenges as the first.

There were minor difference in the machines. For the longer Wiesing section contracting team Porr and Max Bögl used a brand new machine with a 2-chamber system where the rear working chamber contains a compressed air bubble for fine regulation of the tunnel face pressure particularly at difficult spots, where as little as 13m of overburden was present. It started work in June 2007.

A contracting group of Strabag, Züblin and Hochtief used a rebuilt machine originally from Kuala Lumpur for the shorter drive which began in November 2007. This machine had hydraulic rather than electrical drive and used a partitioned base element which divides the face chamber in two as a defence against clogging by excessively silty clay ground. This machine faced a maximum 3 bar pressure but came within half a machine diameter of the surface at one point.

Both machines had to handle a heterogeneous mixture of ground types including the capacity to cut and crush larger rock pieces and boulders. Both finished in good time, the first longer drive in February this year, six month early and the second drive in April. The machines drove in opposite directions, so that each could finish at the central drill and blast tunnel which was convenient for reception chambers. Outer shields from the machines will remain in the tunnel walls as the internal components are stripped down and removed.

Apart from the machine technology itself, both drives involved significant use of jet grouted ground stabilisation, forming grouted "umbrella" arch shapes over the tunnel line at significant points underneath bridges and motorway embankments. One of the most important was under the abutment of a century old bridge crossing the river at Wiesing (see figure 1) and of major local tourist importance.

A large number of shafts – eleven on the Wiesing contract and five more on the Jenbach section were also needed for emergency tunnels. Each was made as polygon of diaphragm wall panels, excavated underwater and sealed with base plug slab at up to 35m deep. Short pipejacked connections to the main tunnel, using Herrenknecht slurry machines ran anything from 20m to 137m and were connected at the end by "NATM" excavation within a block of solidified ground produced by piling, diaphragm wall methods, or jet grouting. Twice these did not fully seal the ground and ground freezing had to be used to finish the connections.

Left: **The complex jet grouting "tube" at Stans to stabilise the ground**

Jet grouting really came into its own on the next section of the route, with perhaps the most complicated geometry on the alignment as old and new rail came together. For this part the now at-grade line dips back into a cutting and then into tunnel, the first 780m long section carrying the new line beneath the town of Stans, close to the river.

Above the new tunnel sits a realigned and now parallel section of the old railway in a tunnel box, with upper and lower railways both passing on a skew underneath the A12 motorway bridge and part of its embankment. To further complicate matters, two small tributaries of the Inn enter the river at this point requiring landscaped culverts at right angles slotted through the two tunnels (see aerial photograph).

Herdina says that a TBM was contemplated for the section but for such a short drive would have been very expensive, though in the end perhaps not much more than the complex grouting selected. The idea for this was to improve the ground beneath the motorway and town by jet grouting.

This did not produce simply a block in the ground. Instead precision control was used to make a "tube" of solidified ground, through which the tunnel could then be bored or rather excavated.

"The idea was to mix the ground with cement grout through jet grouting to produce a 2m thick annulus" says Marco Ziller the project engineer for Italian specialist ground engineering company Trevi which did the two year long project.

"The mixed ground hardens to a lean concrete strength of perhaps 5N/mm2 which was the client's minimum, though we averaged more like 10N/mm2. But because it is a ring it will be very strong and resist the movement of the ground around it when excavating inside."

It also needed to be watertight, or close to it, with no gaps. To do that meant several things had to come together. Firstly the grout drilling would have to be very precise, which meant tight control of the drill strings and of the pressures for the grouting injection. Trevi has developed techniques to allow this with millimetre accuracy says Ziller, using electronic position detectors within the drill string, combined with

Left: **Drill and blast on the longer tunnel section from Stans to Terfens village** accurate measurement of the drill position at the surface.

Second, a precise model of the pattern of hardened ground had to track the build up of the ring. For this Trevi developed a 3D modelling software specifically for the job, using the drill measures to calculate the shape. A copy of the program was passed to the client so that BEG's engineers could make their own checks.

But all that would be useless if the grout did not stay put. Unpredictable mixtures of gravels, silts, sands and boulders in the ground made it difficult to assess the dispersion. So too did the groundwater saturation. "And you must remember it is moving; not as fast as the river but significantly, which means the grout can wash out before it has set" explains Ziller.

Trevi's team devised a six point grouting system. Instead of a single drilling, each grout column is made up from a ring of six drillings. "You do three alternate positions first and then the positions between," he says. The second three act as infills to compensate for any washout.

A final drilling is made in the centre of the hexagon. "By now you have a ring of grouted ground which acts as some protection from the groundwater. By pumping a higher pressure in this central injection you can fill the void completely, 'repairing' the outer six at the same time."

The drill sequence then uses these clusters to build up the shape of the tube in the ground.

All this was tested beforehand on a full scale site mock-up, with excavations to inspect and diamond core drilling to assess the results. Trevi used multicoloured grouts to see just what the interaction was in the ground.

For the actual job Trevi worked from the surface for the drilling, a substantial amount from the side of the motorway, which is one of Europe's busiest, which required nearly 30 different traffic patterns.

The result was good. The tube was made in short lengths with jet grouted partitions across the tunnel line to separate them. Each was tested by pumping out the groundwater to assess inflow and leakage which was minimal. "The client wanted 5lt/sec and we mainly achieved 2lt/sec" says Ziller.

Excavation was carried out within the ground "tube" using compressed air and conventional means. The existing line was then added using cut and cover methods to position it above and the remaining concrete structure completed.

The five year project was the longest tunnelling contract on the scheme says Pellizzari.

Above: Grouted tube stabilisation was used substantially in loose ground

From this complex section the line runs on into a second major rock tunnel, 8,380m long. "Just over 3340m was in hard rock, mostly Dolomite, and the rest in loose ground" says Pellizzari "a complex mixture. The geologist was amazed."

Straightforward drill and blast with Atlas Copco jumbos did the rock tunnel section which contained a 2km long extra wide profile where the tunnel is 17.4m across and 12m high to contain three tracks. "It means we can have a passing place without using space in the valley" says Pellizzari.

The soft ground, comprising alluvial and glacial deposits in terraces was excavated with extensive use of forward grouted tube roof support in a single layer and for some low overburden sections in double layer. A 500m section of forward dewatering was needed and a short 127m length of compressed air excavation underneath a concrete slab where the line passed a shallow valley. Contractor for the €139M (US$208M) project was a grouping of Strabag, Hochtief and Züblin, working from August 2003 until a November 2007 breakthrough with another year to finish the tunnel. A small length of mountainside gallery was next before the last full tunnel section of just over 4km which was also done by compressed air. Excavation was within heavy sheet piled walls, with a concrete slab above and a concrete box built inside. The top down method was used because it was the least disruptive on the village of Fritzens and other dwellings.

The contract, also with a joint venture of Strabag, Hochtief and Züblin, included complex work underneath the station at Fritzens. "It was not possible to put a slab on the lines there so a forward jet grouted umbrella arch had to be made from the compressed air excavation approaching the station" says Pellizzari. He thinks it is the first time the techniques have been used together.

"There was some trepidation since disrupting the lines above would have blocked much of central Europe's freight transit" he says. A computerised real time monitoring system was used with liquid relative movement gauges and laser absolute level measurement on multiple points above. Engineers from the Strabag group doing the work could constantly check the impact of the grout injection pressures, as could BEG.

The section is being completed with a cutting ramp and a short surface run before connection back into the existing rail. Work started in March 2005 and finishes at the end of this year.

Tunnelling across the whole project has gone well, both on schedule and within budget once inflationary factors such as the steep steel price rises are taken into account, says Pellizzari.

Currently the focus is on completing the inner linings and some cut and cover work, and track installation, which will use a mass spring anti-vibration system from Austrian company Getzner with concrete track slab supported on point bearing pads. Signalling and electrical work is underway too with a completion for high speed testing in early 2012, followed - all being well - by opening later the same year. T&T