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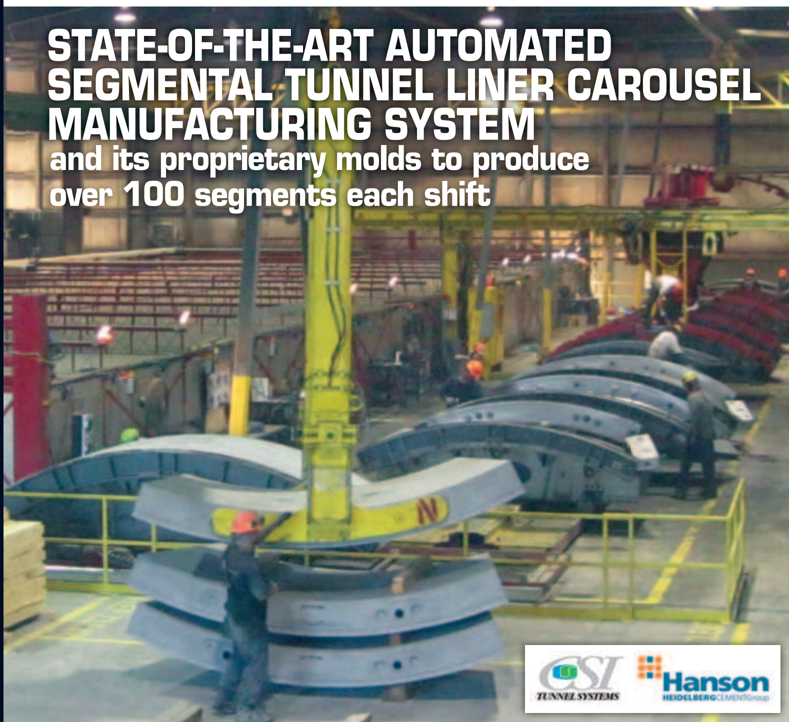
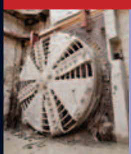
STATE-OF-THE-ART AUTOMATED SEGMENTAL TUNNEL LINER CAROUSEL MANUFACTURING SYSTEM

and its proprietary molds to produce over 100 segments each shift



SEE PAGE 5



MOLEY'S BREAK THROUGH

SPADINA PROGRESS AND OTHER NEWS FROM AROUND THE US AND CANADA

SEE PAGE 17

ARE WE HAPPY YET?

CDM SMITH'S MIKE SCHULTZ TALKS ABOUT ALTERNATIVE DELIVERY METHODS

DETAILS ON PAGES 20-21

CUTTING EDGE ROUND UP

HIGHLIGHTS FROM A SUCCESSFUL PRESSURIZED TBM EVENT IN MIAMI

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June/July 2012

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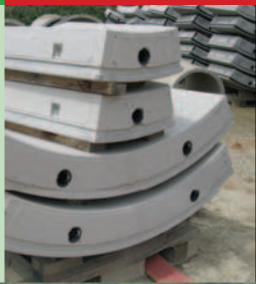
SEE PAGE 6

TJ WORLD NEWS

HIGHLIGHTS FROM THE TJ WEBSITE'S DAILY NEWS SERVICE

SEE PAGE 26



SFR LINING DESIGN ISSUES

MODERN DESIGN CHALLENGES FOR SFR SEGMENTAL LININGS

SEE PAGE 43

PROBE DRILLING

SUCCESSFUL TBM PROBE DRILLING AND PRE-GROUTING EXPLAINED

THE SPARVO TUNNEL MEGA TBM

THE FUTURE OF SEGMENTAL LININGS VIEW FROM ACADEMIA

ANYONE WHO HAS DRIVEN in Italy knows the dramatic multiple viaduct-tunnel sequences that carry many of the scenic autostrada routes. Italian engineers have become some of the world's most skilful in creating hundreds of these bores through the jumbled and twisted strata of the country's Alp-formed mountains and hills.

For the roads in particular, with large cross sections to carry several lanes of traffic, this has meant traditional excavation. Over the years the Italian industry has seen the development of multiple techniques for face and bore support in often chaotic ground, and with it, increasing specialist knowledge of the technical challenges.

But one of the latest projects has turned to the TBM. It is a choice made possible by the development of ever larger machines, and in this case, a true giant of 15.6m diameter, to date the biggest TBM ever made. It may be overtaken soon but for the moment a Herrenknecht EPB, christened Martina, is the world record holder.

The monster machine was not the first

option. Like nearly a dozen tunnels on a new alignment for part of the A1 autostrada, Italy's spine motorway from Naples in the south to Milan and Turin in the north, the 2.6km twin bore Sparvo tunnel was planned as a conventional excavation. A sister tunnel, the Val di Sambro, which starts just to the north across a 500m viaduct, is part of the same contract package and proceeding with conventional methods.

But contractor TOTO Costruzioni Generali managed to convince the client, motorway operator Autostrade per Italia, and its engineer Rocksoil from Milan, that a TBM drive would be a better option for the Sparvo tunnel.

"And we said that it could be done at no additional cost to the client" says project engineer Lorenzo Scolavino. The contract value is US$426M with the Sparvo Tunnel accounting for US$188M. The machine cost with all the fittings is about US$75M.

The reasons are twofold. Firstly, the geology of the ground in this section is as complex as any on the 40km realignment to upgrade a twisting and congested road section between Bologna and Florence. It is in the Appenines, which are a mass of mixed sandstones, clays, porphyrite, limestone and more, often layered and quite pushed around by the tectonic movements that heaved the Alps high in the air just northwards. Substantial support was envisaged including areas of consolidation grouting, heavy anchoring and arches, and significantly thick concrete lining work.

For the first time instead, the option of using a machine is available, as bigger diameters have been achieved. It offered the advantage of speed compared to the painstaking inching forwards the soft and mixed ground would demand by conventional methods.

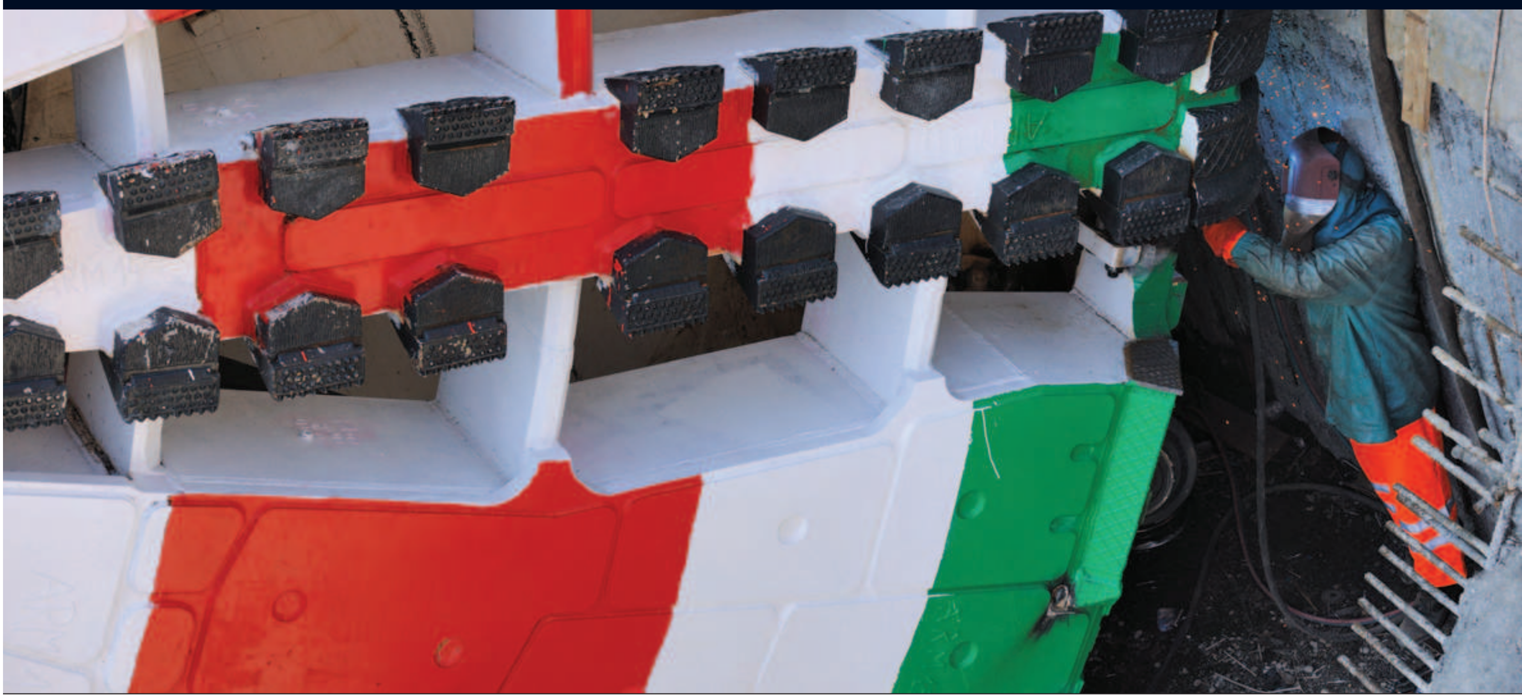
"We think it can make over 400m a month compared to the 20-30m or so possible otherwise" says Scolavino.

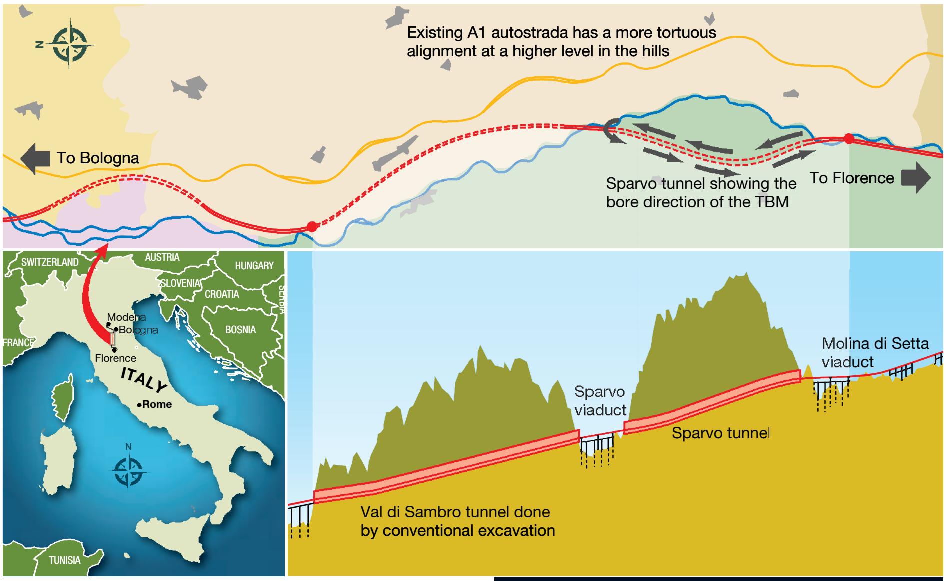
But the machine also offered another significant advantage. The Sparvo section is known to have methane in the ground, the highly explosive "firedamp" which all miners fear for good reason. A machine could be designed to accomodate the danger, sealing the gas outside and using a special enclosed

The central ring of the cutterhead was only just able to traverse the site approach roads

SPARVO GIANT
Worlds biggest TBM

The world's biggest TBM has been getting into its stride in Italy's jumbled Apennine mountains. Report by Adrian Greeman



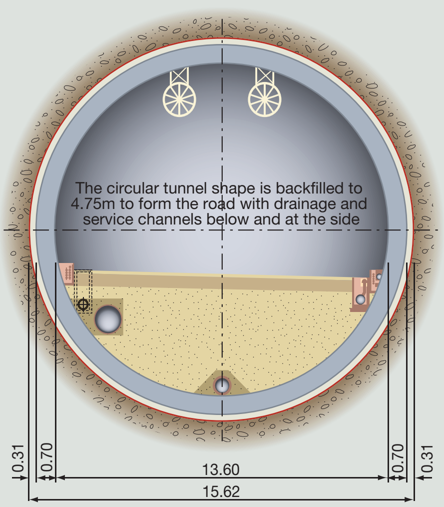


spoil removal system to vent any entering gas safely away. The sealed progress of the TBM also allows for a completely watertight tunnel, whereas an excavated bore would have needed drainage systems to relieve pressure. Overburden here is up to about 100m.

But such a large TBM has presented its own challenges, not least in getting the equipment to site, launching the machine and making the enormous segments it requires. It also requires a special turning area and equipment for the transition between the current bore towards Bologna and the return carriageway. Each has two lanes and a hard shoulder emergency lane.

The first problem was preparing the portals, says Scolavino. "We had already made conventional portals areas, because initially in 2008 the project was to be done by conventional means."

Tunnel cross section and (bottom) the giant segments on the tunnel transporter



The piled wall in the loose weathered debris of the start area had to be removed again once the decision was made in late 2009 to go with the TBM. "It was anchored back into the ground" he says, "but anchors would have got entangled in the cutterhead."

A 41m deep start chamber was remade in the area instead using jet grouting and bored piling, roofed with a concrete slab to form a concrete box. The end of this chamber was filled to 80% height with soft concrete for the initial cut of the machine as it pushed off the enormous reaction frame.

"At the far end, we also removed the anchored wall and used 1200mm diameter jet grouting to make a 31m long reception area for the machine" he adds.

As well as the start chamber a 150m long semicircular concrete trough was built for the machine assembly. This was on sound ground and was made with heavily reinforced concrete between 1.2m and 1.5m thick.

"We also had to build the viaduct outside the tunnel which links the road to the next tunnel because this gave us a route in for the components" he adds. The 550m long steel deck viaduct is one of two which form part of the overall contract. The other is at the north end of the job between the Sparvo exit and the Val di Sambo tunnel, this one of 580m length.

The contract also included making a network of mountain access roads which all have to be removed at job's end because the site is part of a nature reserve. It lies in the 1000m high mountain spine of the Appenines some 40 to 50km south of Bologna.

The largest of the components to negotiate these roads was the central section of the cutterhead wheel, a massive 200t element of just under 9m diameter. It required special

Support for the world's largest EPB shield.

Galleria Sparvo/Italy. The approximately 2.5-kilometre-long Sparvo tunnel is situated between Sasso Marconi and Barberino del Mugello. With its twin-tube construction, each housing a three-lane motorway, it expands the busy stretch of the A1 between Bologna and Florence.

H+E is involved. Besides the challenge of transporting the huge amount of spoil from the world's largest EPB shield, the entire construction had to be designed in accordance with ATEX guidelines, because the tunnel leads through layers that contain methane. A complex task – not least in terms of explosion prevention.

The naked facts:

- Tunnel diameter: 15,55 m
- Conveyor lenth: 2 x 2.750 m
- Capacity: 2.000 t/h
- Installed power: 3 x 355 kW
- Belt storage: vertical
- Belt storage capacity: 470 m
- TBM: EPB
- Installation: 2011

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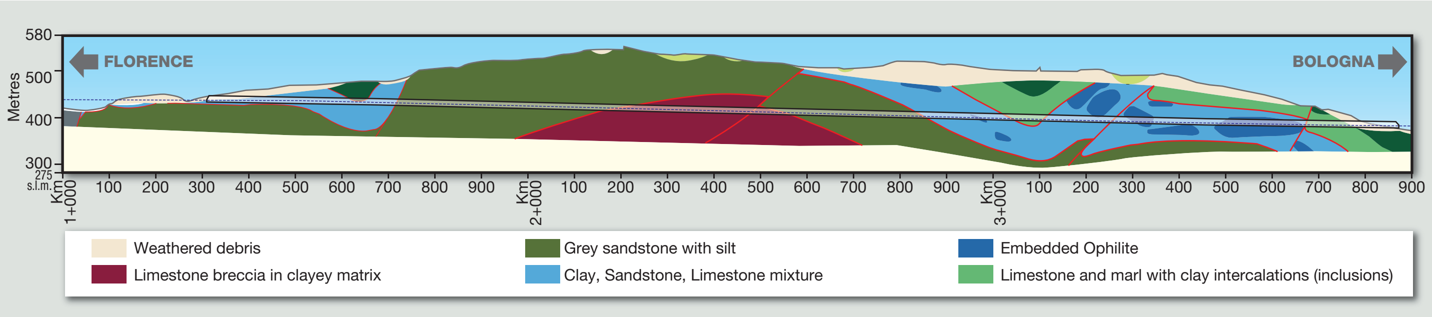
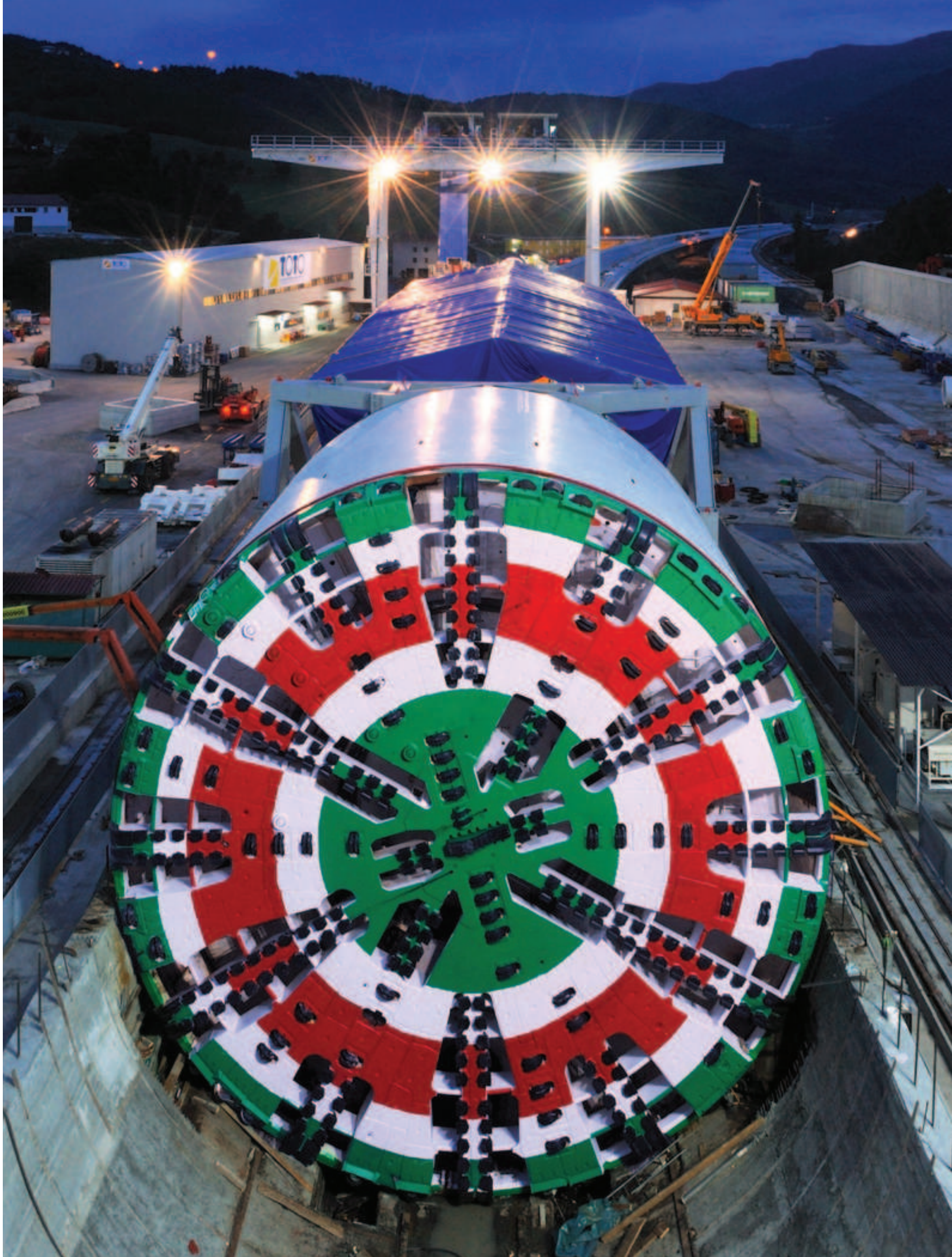


Above: The longitudinal section of the Sparvo Tunnel

Left: The EPBM has impressive torque statistics

Main Pic: 'Martina' the 15.6m Herrenknecht EPB readies to launch



transport arrangements of its own on multi axle transporters. "And clearance on the roads in was just a few centimetres" says Gianluca Comin, a recently graduated engineer and one of three assistants to Scolavino.

A large portal crane, itself needing four mobile cranes to assemble it, was installed on rails outside the tunnel entrance for assembly of the TBM when its major components began arriving in 2011. Like everything these are on a giant scale; there are some four motors alone for the 6m long screw conveyor unit and another 50 in total for powering the machine cutterhead. "Actually there are 12 electric motors, 24 hydraulic pumps and 38 hydraulic motors" says Comin. Power demand is about 12000kW. Meanwhile a purpose built factory for segment construction was being established nearby the site, on a area that will be used later for a motorway service stop once the road is complete. This factory is also on a large scale, producing massive 17t segments, each 2m long and 700mm thick. A complete ring requires nine in total plus a half key. The Internal diameter is 13.6m which means the exterior is 15m.

Segments are made in completely enclosed steel forms explains factory manager Gabriele Trovarelli, using hinged lids to contain the concrete rather than have the top trowelled, as in many plants. The forms, from Italian maker Euroform, must deliver a tolerance of 0.5mm and are checked every three to four weeks.

These rail mounted forms are filled by an automated hopper at the batching plant and then sit in a relatively cool steam curing line for 12 hours before being lifted out. After another day in the factory storage they go outside to harden for 10 days before travelling to the machine.

The segments are transported to the machine on a purpose built rubber tyred transporter which holds one complete ring – French maker Techni Metal Enterprise supplied this US$627,000 unit which is a little like a mini-car transporters. A second transporter for the second drive, which requires a longer route around through the first bore, is being supplied by Italy's Comtec which also provided the big portal crane outside.

A crucial element of the machine assembly was putting together the enclosure for the back-up train conveyor. This is a specially designed feature to contain any possible methane. Essentially the EPB's pressurised excavation chamber will hold any gas behind the bulkhead. The screw conveyor itself is sealed and then enters a sealed box enclosure for the longitudinal conveyor line along the machine.

"It is a double sandwich containing over-pressurised air between two skins" explains Scolavino. "That way if there is a puncture any methane is pushed back into the interior."

Large volumes of fresh air are blown into the box enclosure which dilute any methane as it passes along. A maximum of 110m³/sec is supplied to the tunnel from two Fläkt Woods fans, though normally they work at 45m³/sec. This provides 67m³/sec in the TBM, 22m³/sec in the conveyor and 6m³/sec for the work chamber. By the time spoil reaches the cross conveyor on the back of the machine, it is safe to end the box enclosure.

"But there is a wide variety of gas detection instrumentation on the machine systems, and anti-spark installations" Scolavino says. One man is assigned as safety monitor also.

Once exiting onto the cross conveyor the spoil tips onto a 1.2m wide tunnel conveyor supplied by Herrenknecht daughter company H+E Logistik.

The tunnel conveyor is extended every 200m of drive, which requires a stoppage says Scolavino, during which time the cutterhead tools are checked. To enter the emptied spoil chamber means waiting for gas to disperse, usually between 4 hours and two days. "Though one stop we had to allow four days before it was clear."

The side conveyor finishes at a large conveyor tower just outside the portal where it discharges onto a second conveyor from Marti Technik. This is a 1m width belt carrying the spoil some 1.9km to a special inspection area next to the segment factory.

Giant segments being lifted at the production plant.

Bottom: Testing the air cushion frame

"We have to check the spoil quality here before sending it to final disposal which is along a river valley" says Scolavino. Requirements are tight because the river is a main feed for Bologna's water supply. The site is about 15km away and transport is mainly by truck though there is also another conveyor near the final site which is loaded by trucks to distribute spoil further on.

Progress on the machine took a while to pick up after it began driving in late August last year, with an initial 64m achieved in September and 266m in January. But in March it was hitting its stride with 408m and just around 375m in April and May. Each ring advance produces some 400m³ of spoil, which is around 1000t. At full pace the machine excavates about eight rings daily which means dealing with 8000t of spoil.

Difficulties causing hold-ups include a squeezing effect in the clay and a tendency for the alternately layered clay and sandstone ground to create large half metre size blocks in the spoil. "These pass the screw conveyor OK, but can damage the machine and tunnel conveyors" says Scolavino.

"We also had a two month stoppage initially because of hardening and clogging of the clay" he says. Minerals in the clay proved to be heat sensitive and particularly at the centre of the cutterhead where friction and the motors both caused temperatures increases.

"The solution was to add six more nozzles to inject water in the middle along with the foam treatment which is already done by eighteen nozzles" he says.

Meanwhile the squeezing is handled by using a a fairly large annulus, some 300m wide between the 15.6m excavation diameter and the ring exterior. This is filled with a two part cement bentonite grout injected from the tailskin on the TBM head unit.

Now the machine is reaching the end of the first drive, the next complication this summer is the turning operation. The machine makes to drives, first north and then back again for the southbound carriageway. But how to reorientate such a giant machine is a challenge in itself.

The answer is a special cradle using a hovercraft like principle to lift the giant 2700t weight on air "cushions". It can then be slid carefully around.

Herrenknecht offers a system for this but Toto has decided to work with equipment maker Palmieri, well known for manufacture of cutter discs, and in fact the chosen supplier for "Martina". By chance its factory is in the hillsides nearby. "They have designed a steel frame unit, two of which make up a circular shaped base frame for the machine" says Scolavino. Each unit has eight large circular rubber rings beneath which each are inflated around a central pad. As air reaches around 4 bar it spills out of the rings onto the pad creating a thin air layer which reduces friction.

Eight units, with eight pads each, will support the TBM head. A test carried out while TJ was visiting showed four of the units lifting 1100t of kentledge steel at the Palmieri works.

But the units require a flat concrete base to be usable, so on site a 1m deep concreted area is being formed at the reception portal extending across to the start portal opposite, On this platform a 400mm thick flat floor must be cast. "It is not quite a 'superflat' floor, as they have in warehouses, but we still have to use a laser levelling system to make it" says Scolavino.

Scolavino says the Palmieri units are shallower than the Herrenknecht system and require less excavation for the pad.

A second circular concrete trough will support the TBM train behind the head once it goes through its slow motion dance around. The same air pads will be used to move the backup train, but with extender beams between the air pad units.

"It will take about three months to move it around and restart" thinks Scolavino. The machine must then drive back with an estimated finish in early 2013.

That this is a lot faster than the traditional method is apparent from comparisons with the drive on the Val di Sambro tunnel. Here rates have been between 20m and 50m a month. The tunnel has also suffered a hold up because it passes through an active slide which began moving at the end of last year. Work has just restarted.

Surface effects on the TBM drive have been negligible, though in the last month one building is reported to have shown settlement of some 40mm. It is unclear at present if this is the drive, or an effect of two recent earthquakes which saw significant damage to Bologna.

Once the second drive begins the first bore will see the road bed built up. After drainage is installed with a filter layer around it the contractor will use selected and graded spoil at fill material to backfill to a maximum 4.75m depth where the road will be built. "It is very wasteful filling it all up again" laughs Scolavino. But anyway, more efficient than traditional methods.