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Oct/Nov 2013
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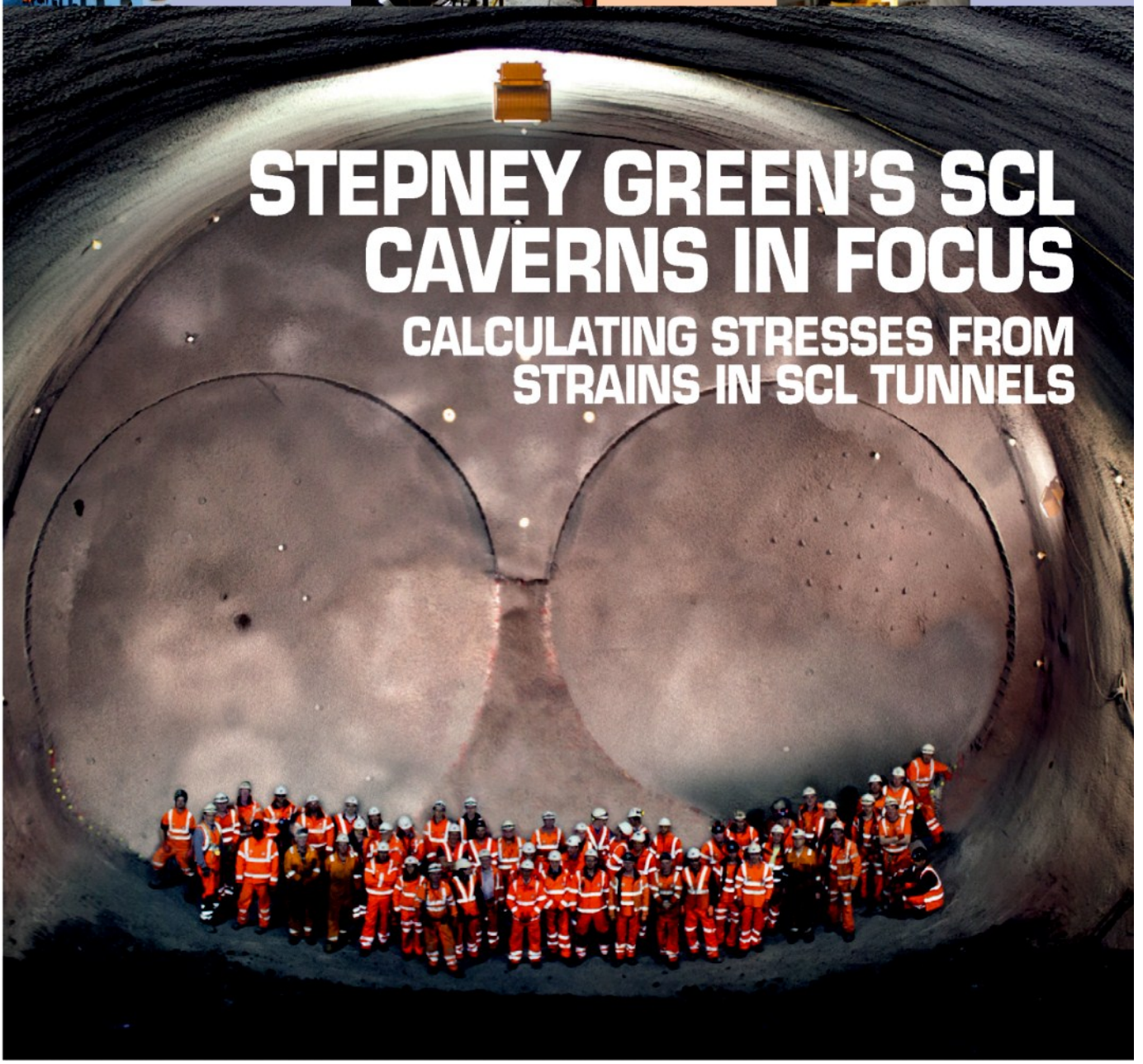


STEPNEY GREEN'S SCL CAVERNS IN FOCUS

CALCULATING STRESSES FROM STRAINS IN SCL TUNNELS

Sparvo revisited - turning the BIG MACHINE

A major turnaround operation for the giant TBM making Italy's twin three lane Sparvo road tunnel has helped complete the boring operations in good time reports Adrian Greeman.

NO INNOVATION is without its worries, especially when a big project depends on it. So for the engineers on the Sparvo tunnel in Italy the turning operation last winter for their big TBM was a particularly fraught moment. The team making the autostrada tunnel (TJ June/July2012) was confident that the method they had devised to swing the machine head around was a good one, but it had never been done quite this way before. "Normally you would dismantle a tunnel boring machine to some extent and then use cranes and trucks to move it into a new position," says project engineer Lorenzo Scolavino for the contractor Toto Costruzioni which is building the new motorway connection. "Then you reassemble and start the new drive." It is quite common to do a second parallel bore this way, either boring in the reverse direction or taking the machine back to the original starting pit for the second drive.

For the 2.6km long twin bore Sparvo tunnel the machine needed simply to flip round by 180 degrees and head back. But this was easier said than done, because the Sparvo machine is no ordinary TBM; at 15.6m diameter it was the world's largest at the time – two even bigger monsters have now claimed the record – and remains one

of the largest ever made, certainly too big for conventional craneage. Dismantling and reassembling it would have needed eight months work or more.

For the rotation of the TBM therefore the Toto team had developed an air floatation system based on the hovercraft principle. A proprietary system from Herrenknecht was an option initially but was ruled out for technical and cost reasons. It was too large and deep says Scolavino.

The system meant that the 2700t TBM head could be disconnected from the back-up train but would be left as an intact unit. This would then be supported on a special undercarriage which would be fitted with air cushion lifting pads. Compressed air blown into the rubber pads would create a thin layer of trapped air underneath the assembly, supporting it and reducing the friction effect hugely.

"We estimated that you would reduce the friction so much that it would 'weigh' effectively only around 30t" says Davida Albricci, one of the site engineers. Ordinary dump trucks would be able to pull the load around.

So it proved eventually though not before the contractor had lived through some worrying moments when it looked as if it might not work.

Turning solution

As explained in TJ last year, the system was worked out in conjunction with tunnelling equipment and TBM cutterhead disc manufacturer Palmieri. The company happens to be based in the same hilly region through which the new A1 autostrada bypass is being driven, to improve the notoriously dangerous Bologna to Florence section of Italy's main north-south trunk route.

Together with Palmieri, the Toto engineers devised a modular system of steel cradle sections. Each would have two rows of four lifting pads in the steel frame shaped to fit half of the curving base of the TBM profile. Two units facing each other made the whole curve and five sets like this, an entire cradle with 80 pads altogether.

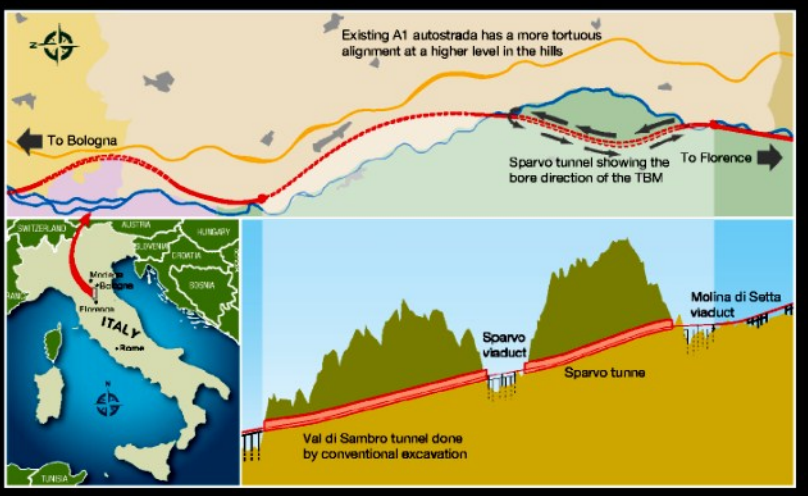
Tests 18 months ago with 2000t of steel kentledge showed the cradle sliding satisfactorily around the Palmieri factory floor, pulled by two trucks. The plan on site was to make just such a floor at the tunnel end portal just before the machine finished its first drive at the end of last summer. A special reception trough was cast outside the tunnel portal, where the TBM could be moved forwards after the breakthrough while supported at the sides and leaving a space below to allow the air units to be slid underneath.

Once pressurised with air the units would then lift slightly and take the load of the TBM allowing it to move out onto the turning area.

"The concrete floor was cast about 1m thick in unreinforced concrete," says Scolavino. "We did not need reinforcement because the area outside the portal is on very good ground, a sandstone which we just had to level." Half the total pad, 30m by 60m, was cast first with the other part by the second portal being done as operations proceeded.

"On top of the pad there was a thinner secondary concrete about 100mm thick," says Scolavino, "which was for flatness." The air cushion produced by the pads under such a huge load is quite a thin layer, no more than a few millimetres thick and it was important to have a very level surface to make sure the air did not escape from the sides too quickly, and that the machine would move evenly. It could jam otherwise.

Groundwater and sand channels in the Westbound Cavern



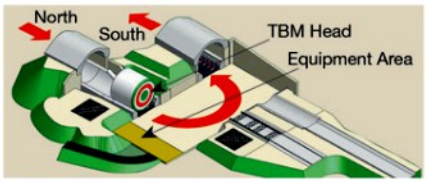
Toto's project, covering construction of two tunnels, the 2.6km Sparvo and the 3.8km long Val di Sambro, is part of a new 40km long section of the A1 autostrada. This is the main north-south spine motorway in Italy running from Turin and Milan in the north through Bologna, Florence and Rome to Naples in the south. The new wider three-lane alignment with a dozen tunnels, nearly as many viaducts and new cuttings and embankment, will replace a difficult stretch of the motorway which runs through the 1000m high Apennine mountains. Tight curves and a two lane configuration without hard shoulders make this notoriously dangerous and also congested.

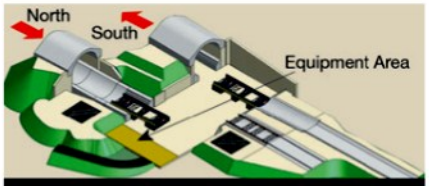
Toto Constructionist's contract covers one of the most difficult sections in complex tumbling geology and is for two tunnels originally to be built by conventional means and two linking viaducts. Toto shares the work on the sister tunnel, the 3.8km long Val di Sambro, excavating 1.6km of its twin bores from the south end.

The contractor convinced 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, even though its three lane and hard shoulder cross section would mean using a giant machine for the first time.

"And we said that it could be done at no additional cost to the client," says project engineer Lorenzo Scolavino. Contract value is currently around €339M with the Sparvo accounting for €150M. Machine cost with all the fittings is about €62M.

The fast progress of the TBM would be far better for controlling ground movement it was suggested, and has now been borne out, particularly in comparison to the difficult work on the conventional tunnel. The contractor had proposed the two tunnels be merged with a deeper alignment to be done completely by TBM, but such a large scale experiment was considered too risky by the client.





Schematic showing the turning principle adopted to transfer the TBM 'whole' from one tube to the other

"We did the top layer with a laser controlled rotary trowel to achieve the necessary flatness" he explains.

So far so good. Unfortunately, it did not work.

The initial problems

The TBM had successfully completed the first eleven month long drive in late summer last year and been slid onto the concrete side walls in the reception trough as planned. The steel lifting units were slid underneath and six big hired-in Atlas Copco air compressors were powered up.

But the machine stuck.

"The problem was that the concrete top layer was breaking up," says Scolavino. It seemed that the compressed air was finding its way into microcracks present in nearly all concrete."

The air pressure being used was enough to expand these cracks and essentially blow the concrete apart. It did not help that the concrete was poured in the high summer temperatures in this region which can reach over 40 degrees, meaning the tendency to crack was greater.

The contractor tried again but this time putting a layer of polymer resin over the finished concrete "to make it impermeable." It still did not work.

The final solution – "an expensive one," says Scolavino with a grimace - was to put down a layer of steel plate across the concrete, that the air could not penetrate. That required significant welding of multiple plate sections, a challenging task in itself as the welding heat could distort the plates. Welds had to be done one at a time to allow heat to disperse and the joints were then cut back and smoothed.

"It did not help that day and night temperatures varied enormously," says Scolavino.

This time it worked. Using constantly hosed on water to add an additional seal, the air formed its proper cushion over the steel surface. Four dumptrucks, two for power and two for position, were able to gently ease the machine out of the tunnel and rotate it around and across the starter chamber for the second drive. The trucks were fully laden giving them the grip they needed on the slippery surface.

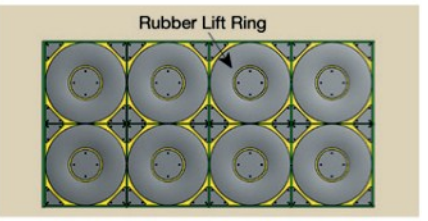
"We had to do it quite slowly as the space for the manoeuvre was quite tight," says Albricci. A particularly difficult constraint was the final movement of the TBM head into the new south drive portal, where the prepared start chamber gave only tens of millimetres of clearance, not much on a machine spanning 15.6m.

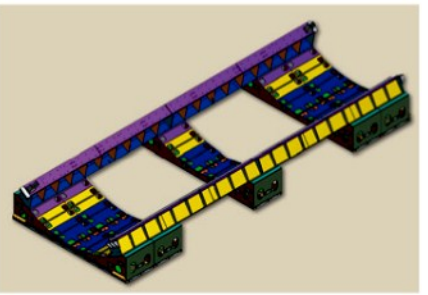
The remainder of the TBM train was then brought around in three sections. For these longer but less massive sections the five pairs of cradle units were split into groups, and attached together with steel beams. The longer "air trolley" had two pairs of units at each end and one in the middle, and could carry out the turning manoeuvres well enough.

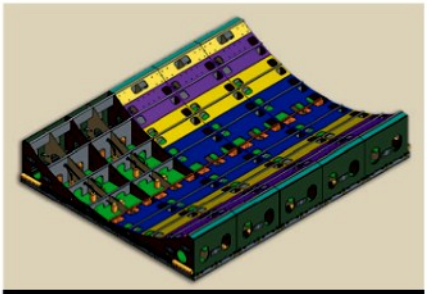
"The TBM train sections had to be juggled around then to fit in the right order," says Scolavino. "It was a bit like those puzzle games you play with coloured squares and one space free to move them about."

Despite the initial hold up with the concrete floor the operation finally went very well he says and the whole TBM was in position for the next drive in just 15 days once the steel floor method had been adopted. Even allowing for the problems, the overall turn was done inside the allotted time in the schedule helping catch up some of an earlier delay on the first tunnel drive.

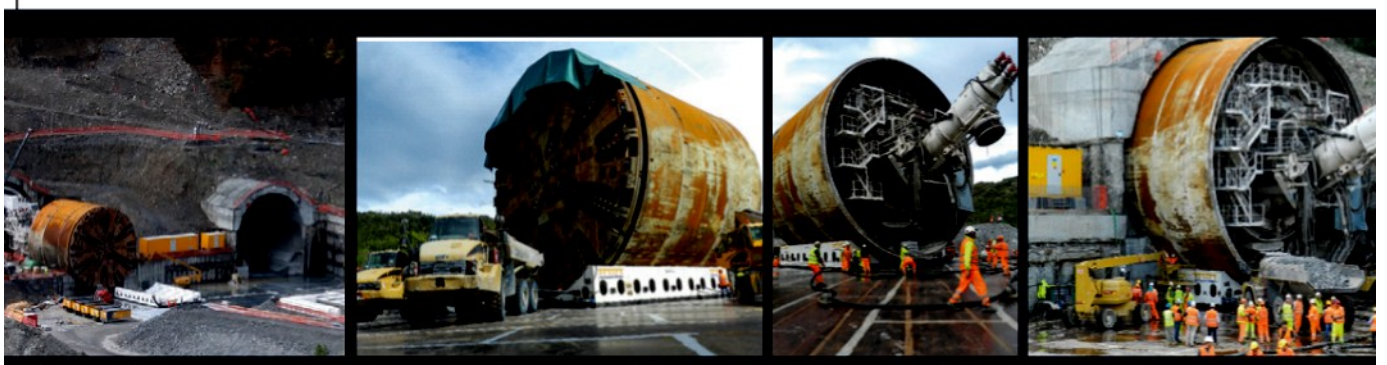
"We were held up for over two months in the beginning because of problems with clogging on the first drive," says Scolavino (see original story TJ May 2012). Clay ground in the first part of the drive proved susceptible to temperature effects from friction and motor drive heat, particularly at the centre of the huge cutterhead. Shortly after the drive began in August 2011, it was necessary to stop the machine and make modifications, adding six new water







The 'cradle' with two rows of four lifting pads in a steel frame shaped to fit half the curving base of the TBM profile



Photographic sequence showing the removal, turning, and repositioning of the 15.6m diameter TBM for the second tube

injection nozzles to the centre of the cutterhead.

But this solved the problem and the machine made good progress since, finishing this first drive in eleven months in July last year. The TBM was able to achieve drive rates of around 400m weekly and 408m on one occasion.

The second bore

Drive rates have been just as good on the second bore and with no hold-ups this time the 2600m was excavated in record time, beginning in late December and just eight months to the breakthrough at the end of July this year.

The second drive was carried out as an extension of the first which is to say that the supply systems and muck disposal for the machine have all passed through the first tunnel.

"A second electrical cabin was added on the Bologna (northern) side to ensure correct management of all electric power equipment," says one of the Toto team's young engineers, Gianluca Comin. "Each cable for the 30kV supply for 15kV, lighting and so on beginning at the second drive portal was connected to the first tunnel lines. Optical fibres were done the same way and all supplies for water, air, grout, and foam were connected up as well."

The massive 17t weight segments were also carried along the first tunnel with the purpose built rubber-tyred delivery trucks, one from French maker Techni Metal Enterprise and one from Italian firm Comtec. Each ring comprises nine segments and half key, all 2m long and 700mm thick.

Mucking out also used extensions to the first tunnel conveyor system. As on the first drive the machine has had to face difficult mixed geology and particularly the dangers of methane which permeates the ground throughout the region, so much so that it is extracted in one or two places for local power supplies. It is called "grisu" locally.

To handle this grisu, the on board screw conveyor system was specially designed for gas resistance with seals around the screw conveyor itself to retain gas inside the earth pressure balance head chamber and then a double skin pressurised containment box around the transport conveyor in the TBM backup train.

The box is ventilated with additional air supplies to "dilute" any incoming methane to safe levels by the time the spoil emerges onto a short side conveyor which moves the material onto the internal tunnel conveyor system. The set up of the machine also includes a variety of gas detectors and alarms and spark suppression for any potential danger points.

"There was maximum of about 0.3% gas discovered but this could become much greater by accumulation inside the EPB chamber, perhaps as much as 6%," says Scolavino.

Spoil movement from the machine was by a 1.2m wide H+E conveyor along the tunnel side to the portal where an 85m long transverse section carried the material across to the first bore. It then passed back to the main site on the Florence side through the completed northern drive.

Back at the site there was another system from Swiss maker Marti Technik which originally carried the material onto an inspection area close to the segment factory, some 1.9km away.

"The spoil from the conventional work is OK because the organics are volatile and evaporate after a while"

Difficulties with spoil disposal have occurred because inspections revealed the presence of some more complex organics, including potentially carcinogenic benzenes and toluenes in small amounts. "We did not have any warning about these," says Scolavino.

The additional chemicals have altered the original spoil plans which were to truck the material to a valley disposal site some kilometres away. But that is not a designated site for such waste and therefore the contractor has been obliged to store significant quantities around the site.

Luckily there is some space because Toto's work includes constructing a 90m high 400m long viaduct across a small valley and a section of a second adjoining tunnel being built by conventional means (see box p19). Toto shares this tunnel excavation with another contractor, carrying out some 1.6km of the overall 3.8km length. One more viaduct is also included in its work along with a stretch of at-grade motorway.

"The spoil from the conventional work is OK because the organics are volatile and evaporate after a while," says Scolavino. That means they can eventually be placed on land classified as agricultural. But the TBM spoil contains conditioners which slow down the process.

Discussions with the client, ultimately

Celebrations as the TOTO teams breakthrough on the Sparvo second tube drive at the end of July this year

responsible for the waste disposal, are continuing at present.

The 'other' tunnel

Work in the other project is ongoing, and has gone rather slowly. In fact the contractor has been granted a year's extension for the project which was held up for some time.

The problem is the stability of the ground. The entire area of hills and valleys south of Bologna is geologically complex and with numerous landslide features, many of them partially active and slowly moving. Paving has been suspended on a site access road which was installed as part of site preparations, to the benefit of the local community. "It was needing repeated re-paving because of movement," says Scolavino.

Landslide is one of the factors behind the choice of a TBM; by picking an option that is fast, and installs a ground-supporting lining almost immediately, it was hoped that ground convergence would be minimised and settlement waves and possible triggering of slide movements could be avoided.

Part of the TBM drive was underneath an area with a 80m deep slide and the machine was checked and given new discs before entering its 600m length, so that if possible it would not have to stop.

It has worked in general though there has been some movement, as much as 100mm in some places and around 20mm in the small village on the hillside above. With around 120m of cover for the tunnel the team is surprised that any settlement reached the surface and there is discussion over whether the heavy rains in the past year have triggered some natural movement anyway.

Meanwhile conventional excavation on a second tunnel, one of several which make up the overall A1 bypass scheme has been painfully slow going. Toto began work on this section in February 2010 before the Sparvo had begun and has advance some 1500m to date.

The tunnel has equally significant problems with landslide and work was suspended for about a year because of movements in a village above. "There has been a need to rebuild a couple of the houses and there has been damage to a church."

The settlements and movement have occurred despite stringent restrictions on excavation. Blasting methods are forbidden completely by the client for fear of triggering landslide movements and the

The Hitachi excavator armed with breaker being used to advance the conventionally bored second tunnel

conventional methods, using a Hitachi excavator mounted with a hydraulic hammer, have tight limits too.

Design engineer for the project Milan's Rocksoil, declared from the beginning that the permanent lining work should be kept close to the tunnel face. The invert has to be cast to within 4m of the face and the 800mm thick cast-in-situ lining work has to lag not more than 50m-60m behind the face works. Rocksoil does the first and second stage design with the contractor's

The Soilmec drill rig is being used to install the 40 - 90 rods used to re-inforce the conventional tunnel

own design company InfraEngineering doing the detail design; the design split is the standard method in Italy.

Excavation itself requires substantial support for the tunnel face which is predominantly a flysch of sandstone and mudstone layers, the mudstone less thick than the harder sandstone in most areas. To stabilise this the engineer has insisted on glass fibre rods installed every 18m, which creates a 6m overlap for the 24m long rods. A big Soilmec boom drill rig installs the reinforcement, with between 40 and 90 rods required depending on the geology and convergence measurements,says Toto geotechnical specialist Davida Albricci.

"It takes between one and three days to install the next set of rods and then we excavate forwards in 1m pulls," says Albricci. Lattice girders are installed and shotcreting is done each round for support.

He finds the process time consuming and chafes at the method, believing in the geology it could be possible to go quicker.

Progress for the work was very slow initially, no more than 12m a month at the start though now around 45m.

Like the TBM tunnel an additional problem in the Val di Sambro has been methane gas. Extensive monitoring is required in the tunnel and all the equipment has had to be "explosion proofed". That means special engine covers are required over any hot part, spark suppression for the election contacts.

Work in both tunnels is also now seeing the installation of cross passages, in both cases by conventional methods. There will be eight pedestrian cross passages of 4m width on the Sparvo, and another two vehicular escape routes which require a 10m excavation for a final 8.5m width.

The Sparvo tunnel is also now to be partially backfilled to bring the circular cross section to the road base level for the three lane highway and hard shoulder than fit inside. The contractor had urged the client to keep the space below the road for access and services but the client has opted simply for backfill.

Toto's work includes subbase and base asphalt, but not the paving work and the fitting out of the tunnel. Scolavino is hopeful that the contractor will be awarded this contract as well.

Toto believes its TBM drive has been significant success in proving that TBM work is the best method for driving even large scale road projects. It is the first three lane project done in Italy or most of Europe by machine drive.

It contrasts significantly with the adjoining conventional section. Despite the tight controls the progress of the tunnelling inevitably has meant greater convergence than on the TBM tunnel simply because the ground remains partly supported for a much greater length of time.

"It takes between one and three days to install the next set of rods and then we excavate forwards in 1m pulls"

"The TBM passed very quickly and has its support in place within hours," says Jens Clasen, formerly with the Alptransit Gotthard Tunnel project and then Herrenknecht and recently taken on by Toto to head up its mechanised tunnelling division.

Currently, and somewhat unsurprisingly, he is pushing the case for TBM work very strongly and declares Toto Costruzioni is now a major player in the field.