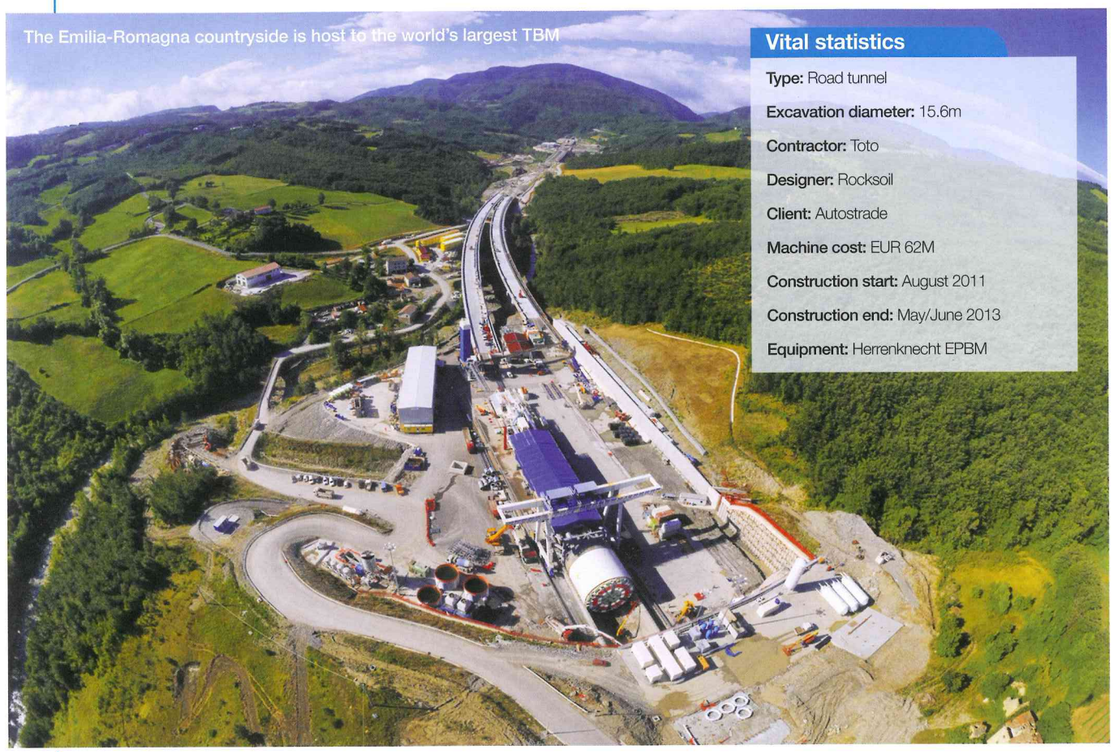


Vital statistics

Type: Road tunnel

Excavation diameter: 15.6m

Contractor: Toto

Designer: Rocksoil

Client: Autostrade

Machine cost: EUR 62M

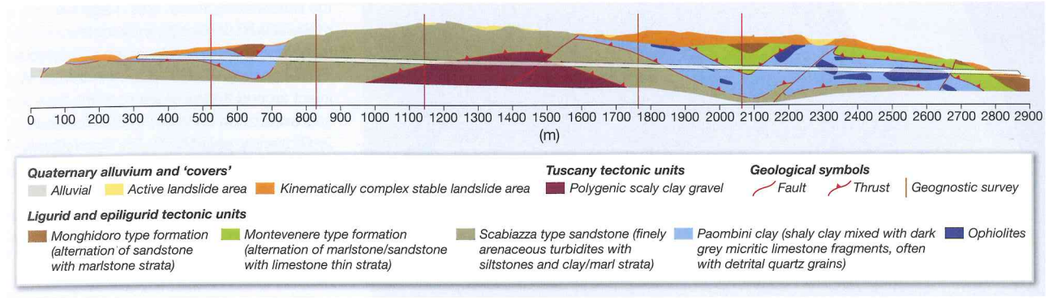
Construction start: August 2011

Construction end: May/June 2013

Equipment: Herrenknecht EPBM

Unleash the beast

Italian contractor Toto Costruzioni Generali has had to overcome an excavation chamber clogged for months with clay, an inefficient approach specified in the tender, and the strain of leaving the site's gourmet canteen each day. Alex Conacher visits Bologna in the heat of early summer to meet Toto project manager Lorenzo Scolavino and his assistant engineers: Maurizio Pepino and Gianluca Comin, both environmental engineers specialising in mechanised shield excavation from Politecnico di Torino



Above: **Figure 1, geological profile**

Nestled in the Apennine Mountains, in the Emilia-Romagna region of northern Italy, the world's largest TBM is chewing through the local clays.

The area's smaller roads curve around medieval villages squatting on small but steep hills. The retired owner of a bell tower hurries out of his garden to show *T&TI* the shell from an Allied tank that passed through during WW2.

Client Autostrada is responsible for Italy's motorway network, and is bankrolling a secondary route through the hills and mountains to relieve traffic pressure on the A1, known as the motorway of the sun.

Italian contractor Toto will execute the majority of tunnelling works on lots six and seven of this 'Variante di Valico' project, which is located on the Florence to Bologna section of the motorway.

The site

The site is located between two tunnels along the new diversion. Cutting away to the south, and towards Florence is the twin tube Sparvo tunnel, excavated by the 15.615m Herrenknecht EPBM, named Martina after Toto founder Carlo Toto's granddaughter, who was born as the company completed TBM purchase.

Sparvo's north tube, almost completely excavated as *T&TI* visits site in July, runs for 2,564m while the south tube will run for some 2,600m.

The neighbouring twin tunnel, 'Galleria Val di Sambro' heads northwards towards Bologna and is excavated by traditional methods; excavator with pneumatic hammers, and supported by steel ribs. The south bore of this tunnel runs for 2,995.5m while the north runs for 3,008m. Both twin tunnels will be linked by viaduct.

Out with the old

Sparvo tunnel was originally specified to be excavated by traditional methods, in the same way as Val di Sambro. The decision to change was an economical one, according to Toto assistant engineers Maurizio Pepino and Gianluca Comin. This is because progress on Val di Sambro has been incredibly slow.

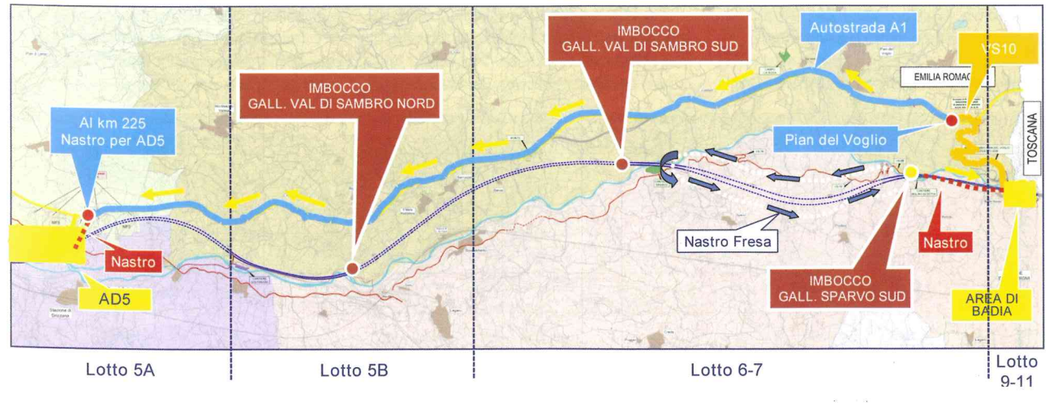
Pepino adds, "It was especially bad in the beginning for Val di Sambro as we excavated the beginning inside a large landslide.

"The geology is very complex on Val di Sambro, and although the tubes are only separated by 50-70m, the face is completely different. One is in limestone rock while the other is in poor soil and completely chaotic, we are facing different conditions metre by metre. The Sparvo geology is also complex and we have encountered highly variable face conditions: massive and stable claystone, swelling clay, medium and highly fractured sandstone, hard and abrasive ophiolites/serpentinites. However a clay matrix was always in place in each face as filler in discontinuities or among blocks."

The difficult conditions meant that client Autostrada was persuaded to allow Toto to excavate the Sparvo galleries with an EPBM. This, following the resolution of the clogging issues, will see Sparvo complete before Val di Sambro.

"This is probably the biggest concern for us," says Toto project manager Scolavino. "Excavation began on the Val di Sambro project in February 2010, and up to now [July] we are about 700m in. CMB is excavating from the other end of the tubes to meet us in the middle, they started some time earlier and are 1km in. We hope to finish by 2014.

Below: **Figure 2, the tunnel locations relative to the work site**



Above: **Methane warning system at the lowest alert level, for normal running**

"Excavation on Sparvo began in August 2011 and will finish around May/June 2013. It's incredible because the ground is actually better for tunnelling in Val di Sambro. But it is this drive that will be the key to finishing close to schedule, Val di Sambro constrains completion and when finished will see the opening of the full Variante di Valico scheme."

Scolavino adds, "The price with which we won the tender was very low, and there is a lot of risk for us from this point of view. Although Sparvo will not finish quite on time - the north tunnel should have completed in June, and we are behind due to the clogging and an injury shutdown - Val di Sambro is the most likely to cause serious delays to the project."

The importance of conditioning

Tweaks to the conditioning system have solved early problems with machine clogging. "From the start of the Sparvo drive in August until October [2011] we had 20 lines of foam to condition the material," says Comin. "This consisted of 15 lines directly to the face, three lines into the centre of the excavation chamber and two lines into the screw conveyor.

"This resulted in the tragic clogging issues we experienced halfway through October. The absence of water in the central part of the excavation chamber caused a complete cementation of the clay, jamming the machine and causing a shutdown. The damage on the sealing system of the main bearing took two months to solve, resulting in around 60 days of jobsite standstill.

"Back in October we were also excavating a particularly adhesive clay. So through a collaboration between BASF Meyco (the foam agent supplier) and machine manufacturer Herrenknecht we added six lines of pure water, three into the centre of the chamber and three to the outer part. We also moved one of the foam lines from the screw conveyor to the centre of the excavation chamber.

"This lasted until January. By this time it had become apparent that the muck was too liquid for transportation and storage.

"For the final configuration the three water lines that were directed to the outer part of the excavation chamber were moved to the central part, supplementing the lines already there. This made the material fluid enough to prevent any clogging problems and with an acceptable consistency to be transported in trucks. We inject around 120m³ of water to the face and excavation chamber in total for each 2m advance, split 50/50. The foam agent forms around 2.5 per cent of the total injected quantity on the face.

"In addition, the excavated material in this 2m advance is 390m³. Our specific volume weight is 2.2 or 2.3t/m³ so this is more or less 900t per advance/excavation.

"The muck was no longer too liquid. The pilot has been able to manage the conditions. Of course, this is after spending two months clogged. It was necessary to totally change the sealing system of the main drive. We also had to remove the material in the excavation chamber with a pneumatic hammer."

The team points out that conditions have varied and that these are only average values, at one point they injected 160m³.

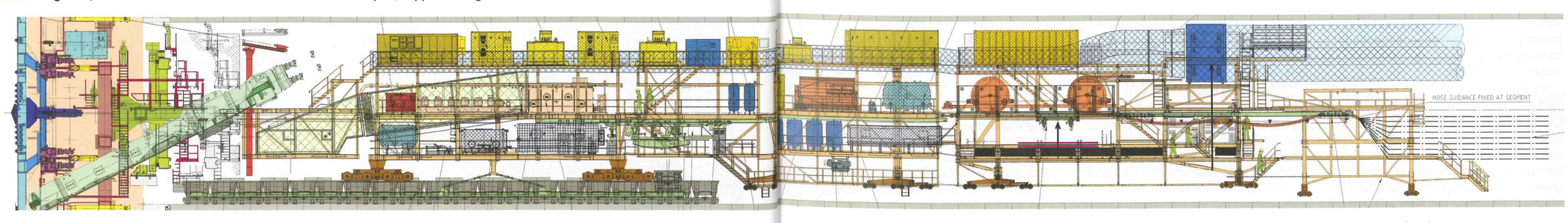
Scolavino adds, "With this finalised system in place and increased experience with the machine, the south drive will surely be much quicker."

Gas provision

In addition to adhesive clay the Apennines are loaded with 'grisou', or firedamp in English - a mixture of flammable and explosive gases, particularly methane. "It is a big problem," says Scolavino, "but no secret, the TBM was designed to cope. The belt conveyor is sealed within its own tube to prevent the gas escaping, and there is an array of sensors and monitoring equipment to ensure the gas does not build up.

"The machine cost was very high, at EUR 62M (USD 77M) and the presence of gas was known, and this guided the design. For each shift there is a man to control and monitor the gas, this is subcontracted to Collins, a company that specialises in this. There are 10 monitors in each section with double redundancy, and the TBM's power is shut down if the methane ever exceeds a limit value."

Below: **Figure 3, Side view of the EPBM**



Comin adds, "The limit varies in each section, with a strict value of 0.35 per cent in the shield, and three per cent in the tunnel. However if the gas gets above one per cent in the tunnel, the pilot has to decrease advance speed, and if this is not done the machine stops automatically. The explosive limit of methane is five per cent."

Scolavino continues, "There is a traffic light-style warning system of green, blue, yellow and then red. Red means evacuate. The belt conveyor tube itself has a double layer casing that is overpressurised so that if there is a hole, the pressure can stop the gas. There is also a special ventilation duct into the tube. The pilot can increase the airflow to about 25m³/s.

Martina the monster

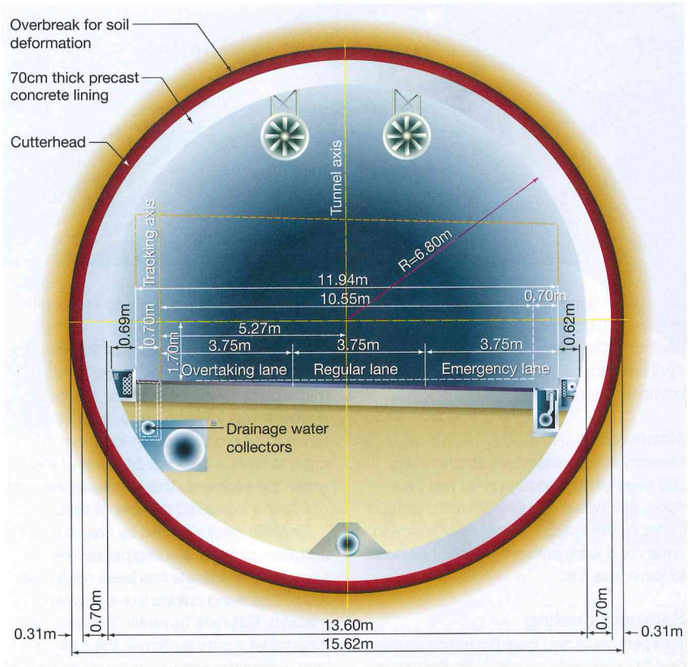
Besides a new belt conveyor tube style to deal with gas, the sheer scale of the project's TBM is not unknown to the industry. At 15.615m in diameter, it was the world's largest TBM at the time of manufacture and also one of the most powerful. Installed power is 12MW, maximum thrust force is 394,850kN at 500 bar, cutting wheel torque is 94,793kNm and total weight is 4,500t.

It is equipped with 76 disc cutters of 17-inch diameter, 216 cutting knives, 24 buckets and one centre knife, a setup to deal with the expected geology of clay with argillite and sandstone.

Pepino adds, "The size of the machine has made working in the tunnel totally different. It is much more comfortable. In most TBMs space is very limited but not here, each workman can fulfill his task in a perfect environment."

The site runs eight-hour shifts, with fifteen workers per shift.

The shield was also designed with a conical shape - with the excavation diameter larger than the rear shield diameter. This was due to fears of squeezing ground according to Comin. "It is 15.615m at the cutting wheel but the rear shield is approximately 15.3m. There is a 300mm annular void, so it is necessary to inject 30m³ of grout to fill the gap. The project value for injected grout is 29.5m³ in a 2m advance."



Above: **Figure 4, tunnel cross section**

The Rheosoil 143 foam agent was provided by BASF, Mapei supplied the component grout and Condat the tailskin grease. "In clays where we encountered swelling, we had to talk with the designer, Rocksoil to accept less grout injection. In places it has been reduced to 22m³, so there has been a convergence of the tunnel around the shield and final lining of 50 or 60mm at the maximum."

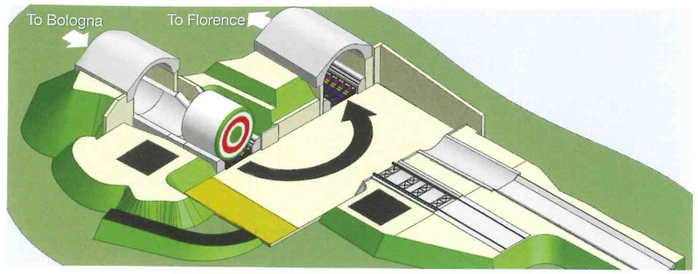
The TBM is linked to a transforming plant near the Florence portal that is itself connected directly to the Italian high-speed rail network. Some 18MW are available, total installed power is 16.8MW, and as of July, 11MW was the maximum power used for excavation, ring build and all normal TBM operations. There are 38 hydraulic motors to rotate the cutting wheel, but the machine can fit up to 50.

Scolavino adds, "Although there is no way to run the TBM if this link is interrupted, it is a national line so we have never had this problem. The connecting line is 132kV and was realised especially for our work. The line has to run approximately 10km across mountains and through forests. We actually had to lay foundations for the transformer plant by helicopter."

Annual power use is 62,000,000kWh, equivalent to a town with a population of 20,000 people.

Performance

In terms of advance rates, Toto managed to



Left: Figure 5, TBM rototranslation

hit a maximum monthly production of 406m in March 2012. It has also seen a week peak of 122m during the week ending 22 April and has on three occasions hit 22m advance rates in a day.

Maintenance

Maintenance is performed around every 200 rings (400m), though wear has been good, and where there is at least one good cutter on the specific cutter wheel track to cover for a worn cutter, the tactic has been to leave it as it is.

Segment casting

Toto personnel and local Romagna workers cast the segments on site. With the largest machine in the world, comes the largest precast lining.

The universal ring is a nine plus key arrangement with a total ring weight of 160t. The segment length in the direction of the machine advance is 2m and the thickness is 0.7m. Scolavino adds, "Perfect workmanship along the production chain is needed for this; at the point of casting, transportation, stacking and placement.

"The thickness has been connected to a series of difficulties, for example the curing process. The tolerance is also very strict, we check this manually by micrometer, and every two to three months, our guidance company VMT also comes to check the Aeroform moulds by laser. The Aeroform moulds are the most expensive, but they have the highest performance."

Bar reinforcement is used, with 110kg used per m^3 of concrete. According to Scolavino, special studies were conducted to design the steel reinforcement to avoid fractures during positioning, due to the weight of the concrete.

A carousel system is in use in the casting yard with four series of 10 moulds (10 moulds to a ring). The design production is 80 segments per day, and the factory works 24 hours a day, six days a week. A baking oven/curing chamber allows segments to be demoulded after 80 minutes. The system has been effective even in temperatures down to -14°C in the winter, with 2.5m of snow.

There are no polyfibres, but the corners of the segments are given extra reinforcement with wire mesh. The bar diameter was lowered twice, from 22mm down to 16mm then down to 12mm in order to have a better distribution of steel within the segment. This increased the cost due to the increased number of bars.

Gaskets were supplied by Italy-based Fip and were glued to the segments. The segment discard rate has been negligible, which Scolavino credits to his segment maestro, Gabriele Trovarelli. Trovarelli also introduced a gate system in the casting yard, where the carousel will only move if all of the gates are closed between the workers and the moulds, greatly reducing the risk of injury.

Turning the TBM

The north and south drives are excavated by the same machine. But with such an enormous TBM, and a small area to turn, an experimental manouever is needed to 'rototranslate' Martina to face the southern drive. The first 20m have already been excavated and lined with steel ribs and sprayed concrete. Design was by Toto and Rocksoil, the sprayed concrete machine is CIFA-manufactured and was also used on the Val di Sambro part of the project.

The process is much like the Tower of Hanoi puzzle. The portions must be shifted through the prepared bays opposite the portals and rejoined in the correct order ready for the southern bore. First the shield will be moved, then the first gantry, then the second, which will need to be moved behind the first and then the two moved behind the shield.

The machine sections will be positioned on special Palmieri metallic cradles, and raised by 80 'Aero-Caster' air pillows manufactured by Aerogo Systems. Toto, working with Palmieri, the company also supplying TBM cutters, will do the move.

A test to carry half the required load was carried out at the Palmieri factory relatively close to the site, which was successful and it was decided to use five cradles to move the TBM. The test area was not ideal however, as there was a joint in the floor which allowed the air to escape and the pressure to disappear. As *T&TI* visited site, Toto was busy casting an incredibly flat concrete floor for the operation, which has a tolerance of a 1mm variation over a metre. This will ensure there is no loss of air pressure during the transition of the EUR 62M (USD 77M) piece of kit. The move will take three months to fully rotate and set up the TBM following the breakthrough at the end of the northern drive on 25 July. The cutterhead was due to be in position for the south drive in August.

Comin adds, "We will commence the south drive around the beginning of November. We also have to assemble the steel launch portal, then disassemble and remount the vertical conveyors, move the ventilation system, install another series of conveyors and two new hoppers."

Conveyors and muck

Marti supplied the project's conveyor system, with vertical storage by H+E Logistik. Once on the south bore, the conveyor system will feed back through the north tunnel to the original system.

The conveyor distributes muck between five storage areas of 5,000m^2 ground space each and 20,000 to 40,000m^3 of total storage, depending on the height of the heap. The divisions are for chemical tests for oil, grease and so on. Once the muck is definitely clean, it can be moved on. A hopper moved between the storage areas.

The muck is combined with lime to eliminate excess water in the material and give a good consistency. Early on in the excavation, the initially selected SLF 41 foaming agent was not working and when the conditioning system was being fine-tuned the material was too wet. This meant it was difficult to store and impossible to transport. The team adds that there was a risk of days of standstill due to the liquidity.

The material will be used for environmental improvements, creating gardens and so on. But the storage on site faces restrictions also. A nearby river is incredibly pure and feeds Bologna's aqueducts. There are 10 enormous water treatment plants to avoid dust contamination in the summer.

Scolavino finishes, "Special mention should go to TBM chief Ulisse Beozzo. Apart from that, there is a prize to finish this job on time, and we will still try to get it."