THE MONTE GIGLIO TUNNEL- BERGAMO (ITALY)

ITALCEMENTI: PROVISIONING OF QUARRY MATERIAL FOR THE NEW CEMENT FACTORY AT CALUSCO D'ADDA

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Abstract

This paper describes the procedures and the techniques implemented by SELI for the construction of an almost 9,500 metres long tunnel, for the installation of a conveyor belt linking the "Colle Pedrino" quarry to the new cementproduction factory of Calusco D'Adda (Bergamo).

The tunnelling will be mainly driven tthrough flyschoid formations consisting of alternations of sandstone and mudstones for the first 8,000 m approximately of the drive, and through limestones locally selciferous for the final 1,500 m of tunnel.

The tunnel was bored utilising a double shielded Robbins TBM with a diameter of 4.88 m, and was lined with hexagonal type reinforced concrete pre-cast concrete segments 20 cm thick.

The work has features that would characterize it as unique: the tunnel route marked by continuous variations inalignmentr and elevation, the definitive installation of a "heavy" conveyor belt to transport the muck, and the difficulty for personnel and materials to access and exit the tunnel – all factors that have made it necessary to use innovative technologies in the field of mechanized tunnelling.

The tunnel portal was located in the area of the Monte Giglio quarry near the cement factory. The tunnel route has a gradient of 11% for approximately 850 m, a shallow rise 1- 2.15% for about 5,800 m, and a final sharp rise, with an ascending slope of up to 21 % for about 2,900 m.

The muck transport was performed by means of a "steel cord" type conveyor belt installed during the tunnelling construction and used as the TBM advanced.

The construction materials needed – concrete segments and the structure of the conveyor belt– as well as the personnel travelled on special trains designed and built to adapt them to the features of the tunnel route.

Beyond providing useful information, the following notes may also be of use for resolving similar problems in the specific application of mechanized tunnelling and in underground works more generally.

Introduction

Commissioned by Italcementi Group, the Monte Giglio tunnel is part of the project to modernize and upgrade the Calusco d'Adda cement factory (New Calusco Project). The old telpherage, which fed the cement factory with lime for 50 years, was no longer able to satisfy the plant's output. However, enlargement was to require considerable investment, but the decision to build the tunnel was conditioned by considerations of an environmental nature: the tunnel remains the most valid solution for reducing the new works' environmental impact. The installation of a continuous conveyor belt inside the tunnel will make it possible to transport a considerably greater quantity of lime at costs much lower than those of the transport systems currently used (telpherage and trucks).

The conveyor belt will be able to satisfy the increased demand for material from the cement factory, making it possible on the one hand to make the most of the new plant's productive possibilities, and on the other to preserve the life of the Monte Giglio quarry, which would otherwise be headed towards quick impoverishment.

The Monte Giglio tunnel is thus of essential importance in this context. Its construction was an absolute necessity for guaranteeing the future of the Calusco d'Adda cement factory.

(See photo 1)

Photo 1

1. HISTORY OF THE TUNNEL

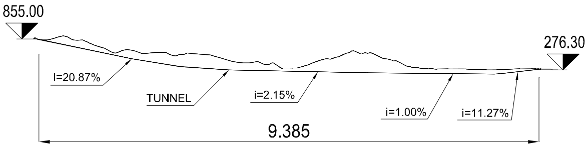
In year 2000, Italcementi commissioned a 9,500 metre long tunnel from “Consorzio Monte Giglio” – a consortium established by Strabag and Del Favero, which built only the first 850 metres of the downward slope. The consortium excavated the first 550 metres with an open TBM, but the passage through a considerable pocket of fine sand led to the collapse of the tunnel crown, making it necessary to abandon the tunnelling method being used. The TBM was thus recovered and work continued with traditional method for an additional 300 metres until the end of the slope, where a large chamber was built.

In order to complete the works, the Client and the Contractor decided to commission the remaining section of the tunnel to a specialized tunnelling company. In September 2003, SELI, after the installation of the new equipment, started excavation with a double shielded Robbins TBM, and on 31 May 2005 reached the Colle Pedrino quarry.

2. THE TUNNEL ROUTE

The tunnel route has an overall length of 9,460 metres, and must overcome a total difference in elevation of 560 metres, rising from 290 m above sea level at Monte Giglio to 850 m above sea level at the Colle Pedrino quarry.

The tunnel route has 4 planimetric curves and 2 curves in elevation. Starting from Monte Giglio, the tunnel begins to curve downwards for about 850 metres at a slope of 11%, then rises gently for about 5,800 metres with a slope varying from 1% to 2.15%. This is followed by the final sharp rise for about 2,850 metres, with a slope growing to 20.87 % (see photo 2).



Tunnel Longitudinal prifile

Photo 2

Between the downward slope and the gentle rise – the tunnel’s most depressed point – a large chamber was excavated, in which the system to pump out the water drained from the tunnel, and a train switching system was installed.

This chamber was also utilised for the assembly of the TBM and it’s back-up.

At approximately 4,600 metres from the Montegiglio portal, in the town of Pontida, a 8 metres diameter, 55 metres deep service shaft, also necessary for safety during the tunnelling phase, was built.

3. GEOLOGY

In the design phase, geological and geomechanical characterizations of the formations crossed through were accurately performed by means of:

- A careful study of the broad bibliography in the literature
- The geological, hydrogeological, and geological-structural surveying
- Direct and indirect surveying campaigns in the subsoil for much of the tunnel route
- Geotechnical tests on site and in the laboratory, on samples taken during probing
- The geotechnical characterization of the terrains and of the rocky mass
- Hydrological characterization by water pumping tests and piezometric readings

These preliminary studies shown the tunnelling to be taking place in flyschoid formations consisting of dense alternations of sandstones, arenaceous lime, and marl, and in the final section in muddy and locally selciferous, conglomerate, and radiolarite limestones. From geomechanical point of view, the formations that are crossed are prevalently in class II and III in accordance with Bieniawsky’s RMR classification (1989).

The geological surveys carried out on a daily basis during excavation essentially confirmed the design hypotheses.

4. TECHNICAL AND CONSTRUCTION PROCEDURES

Given the complexity of the tunnel route, the initial conditions found, the very tight programme of works, and the difficult surrounding conditions, the construction of the Monte Giglio tunnel turned out to be an enterprise of considerable technical and operating difficulty, which made even such routine phases as assembling and disassembling the TBM very complicated. The choice of particular technical solutions applied in some cases for the first time in mechanized tunnelling, such as the materials transport and train switching system, tested to the limit the versatility of the double shield TBM.

4.1 Assembling the TBM and Back-up

The first 550 metres of tunnel excavated with the open TBM and lined with steel ribs and shotcrete, made it indispensable to assemble the machine in the tunnel. The machine was assembled in the chamber at the end of the downward entry slope, 850 metres from the entrance
(see photo 3).

Photo 3

The chamber was in fact suitably sized for the needs imposed by the handling of the large TBM components. Particularly difficult was the transport and the handling of the heavy loads, due to the slope and because of the size difference between the open type TBM, which was 4.5 metres in diameter, while the diameter of the double shielded machine was 4.88 metres (see phto 4).

Photo 4

The TBM components have been transported down the slope by using a specially designed platform equipped with steering wheels and connected to a truck. The back-up platforms were lowered one at a time along a temporary railway track, which has been removed after the back-up assembly to allow the conveyor belt installation.
The mechanical assembly of the TBM, was performed entirely underground, and required the employment of highly specialized technicians.

4.2 Tunnelling

The tunnel was excavated with a double shield Robbins TBM, model 1611-283 (see photo 5).

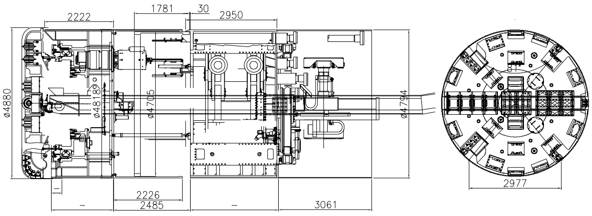


Photo 5

The TBM's main technical features are as follows:

Diameter of excavation:	4.88 m
Diameter of cutters:	17’’ (432 mm)
Number of cutters:	32
Maximum total thrust:	8250 kN
Cutterhead rotation speed:	0-10 rpm
Nominal cutterhead torque:	2367 kNm
Total cutterhead power:	1890 kW

No. of motors and power:	6 x 315 kW
No. of thrust cylinders:	10
Thrust cylinders stroke:	1380 mm
No.of auxiliary thrust cylinders:	14
Auxiliary cylinders stroke:	2200 mm
Power supply:	15 kV, 50 Hz
Total weight of TBM:	390 T

In order to have the possibility of investigating critical areas of the rock mass, the TBM was equipped with an Atlas Copco drill, model COP 1238, which enables probing ahead, and where required, also the forepooling works.

The segmental lining erection is performed concurrently with the excavation and consists of 4 hexagonal type pre-cast reinforced concrete segments, 1.3 metres in length and 20 cm thick. The ring's external diameter is 470 cm, while the internal diameter measures 430 cm. Since they are hexagonal in type, the segments are erected in pairs and geometrically the rings have the characteristic honeycomb configuration (see photo 6).

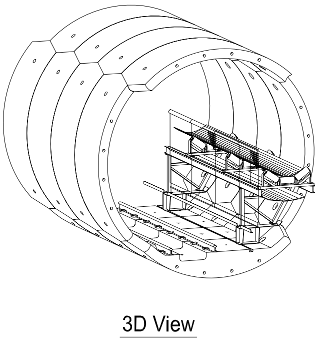


Photo 6

The correct positioning of the segments is guaranteed both by their hexagonal shape and by the use of locating steel rods, which, in addition to enabling an easy positioning, also guarantee the sealing until the containment action of the pea-gravel becomes active. The pea-gravel with grain size of 6-15 mm is pumped behind the segments, between the extrados of the lining and the excavation, in a quantity of about 1.5 m^3/ring.

4.3 Mucking

The permanent conveyor belt, which serves to link the *Colle Pedrino* quarries with the Monte Giglio deposits, was assembled and used during the tunnelling construction phase for mucking out purpose. It was installed behind the back-up as the TBM advanced during the excavation (see photo 7).

Photo 7

The technical features of the belt are as follows:

- width: 800 mm;
- type: steel cord;
- maximum tension: 3,150 N/mm^2
- weight: 28 kg/m
- belt thickness: 19 mm;
- speed: 3.75 m/s
- maximum capacity: 200 ton/hr

A modified conveyor belt configuration was utilised for mucking out during the tunnelling works.

At the Monte Giglio tunnel portal, there were (see photo 8):

Photo 8

- the “belt storage unit” which made it possible to store 400 metres of belt;
- the counterweight tower;
- the motors(2, 630 kW);
- the reducers;
- the drive drum (1,250 mm in diameter);
- the unloading hopper.

Inside the tunnel were installed:

- the structure of the belt, varying in type depending on the tunnel route;
- the return drum connected to the end of the back-up through a car running above the belt's structural frame;
- the unloading hopper to download the material from the back-up's belt to the final belt

After excavation was completed, some modifications were made to the belt. At the end of the Monte Giglio tunnel, the "belt storage unit" – no longer necessary – was disassembled, the gear motors were removed, and the belt coming out from the tunnel was extended to join the main quarry plants' belt. In the tunnel, the car with the return drum and the unloading hopper were disassembled, and the belt's structural frame was extended to the Colle Pederino yard. Lastly, at Colle Pedrino, the belt's drive station was assembled.

The "belt storage unit" and the return drum connected to the back-up were modified as per original design, modification suggested by SELI to improve the production time. This modified configuration enabled to avoid time loss due to the stoppage for installing the belt's structural frame every 200 metres; with the new system, the belt was assembled in parallel with the production cycle by proceeding with installation as the TBM advanced, just as occurred for the lining erection.

The "belt storage unit" could store 400 metres of belt, thus affording the possibility of excavating 200 metres of tunnel before making a new belt joint. The joints were made outside the tunnel at Monte Giglio, and two days were needed to complete the whole operation. Considering that the belt length required 47 joints to be made, there were 94 days of production lost due to this operation exclusively!

The belt assembly was a specific task and was carried out by specially trained personnel.

The proper alignment of the belt structural frame – an essential aspect for preventing belt slippage, was perfectly guaranteed by the use of laser and by daily supervision by the tunnel surveyor.

A team of mechanics was in charge of monitoring the quality of the assembly and continually overseeing the belt for its entire length, in order to intervene in the areas where excessive slippage was taking place.

Lastly, all personnel dedicated to the belt reported to a "Belt Manager."

It may be said that the tunnel purpose, which is the assembly of a continuous conveyor belt, did not provide the possibility of choice with regard to the mucking system to be adopted in the tunnel. Using the final belt for mucking certainly had advantages in terms of putting the system into service when the tunnel was completed, but at the same time it was also a sound solution for bringing the material out given the type of tunnel route with its difficult steep 21% slope. On the other hand, the other side of the coin was the complicated management of a transporting system of considerable size, that was assembled, calibrated, tested, and managed at the same time. The problem faced was the imposed use of a conveyor belt (20 km of belt length, 4 planimetric curves and 2 in elevation) designed not for the mucking out during tunnelling operations but for a definitive use, where "definitive" is understood both for the belt but also for the location in which it is installed. As it proceeds, the excavation of a tunnel continuously modifies the belt's geometry and the state of tension induced onto the belt, thus determining its difficult management in terms of its conduction, both in straight sections and in curves.

For SELI, it was essential to face these difficulties by performing an ongoing technical survey during the work as to the physical effects that can be and that are induced onto the belt, by continuously managing and monitoring the entire length of the belt with personnel carefully trained in the operating method, and by developing a detailed quality control system for the belt assembly. Keeping the TBM's productivity from being excessively conditioned despite the effort in installing the conveyor was one of the hardest challenges of this work, on the same level as carrying out such a complicated project.

4.4 Transport and switching systems

The pre-cast segments for the final tunnel lining, the pea-gravel, and all the materials necessary for carrying out the work (tracks, pipes, conveyor belt structural work, etc.), were transported by trains.

The particular nature of the tunnel route and the slopes made necessary to differentiate the types of trains to be used. In particular, in the initial downward slope and for the final rise sections, special prototype trains were used, called Climbers, manufactured by the Swiss company ROWA in collaboration with Germany's INTRAG (see photo 9),

Photo 9

while in the long, gradually rising central section, a classic tunnel locomotive manufactured by the Swedish company GIA, travelling at speeds far greater than the Climbers, was used.

The Climber trains were specially designed and built to travel in sections, fully loaded, at slopes of up to 21%. The train consists of a locomotive, a flatcar for transporting gravel, and two flatcars to transport the segments (see photo 10).

Photo 10

The various components are equipped with vertical axis hydraulic type motors, and each component has its own drive unit (see photo 11).

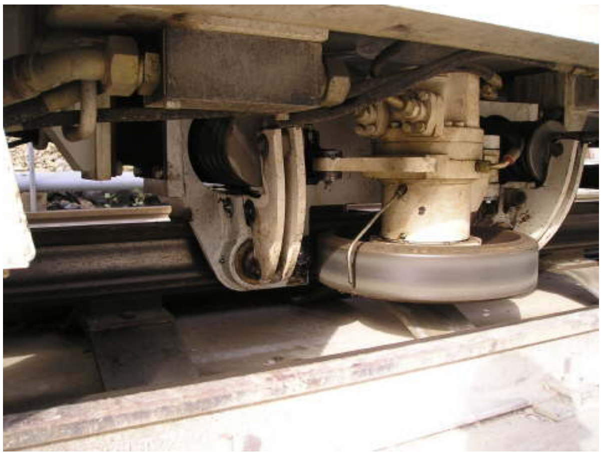


Photo 11

Overall, the train is equipped with 12 opposing hydraulic motors that couple together to act against a central monorail made with an IPN 140 bar. The monorail is mounted at the centre of a classic track, which in this case however performs only the function of supporting and guiding the train. The diesel motor and the main hydraulic pump are on the locomotive, from which the hydraulic hoses depart towards each motor unit. As a whole the system is simple and solid. The only drawback is speed. In flat sections, the Climber can travel at a top speed of 5 m/s, and in rising sections speeds drop to 2 m/s.

The fact that sloped sections have a total length of about 4 km clearly shows that the transport has inevitably impacted the productive cycle.

As for the switching systems adopted, here as well the type of tunnel route – even more than the dearth of available space – prevented the construction of switches for trains, as the Climber cannot travel where the GIA does and vice versa. It was only possible to create stations for transferring materials from one train to another.

In particular, two switching stations using distinct technical solutions were designed. The first was by bridge crane working on the two parallel lines, positioned in the chamber at the end of the Monte Giglio downward slope. The second switching system was deployed in the tunnel, at about metre 5780.

The latter system used a hoister positioned in the ordinary tunnel section, consisting of 4 distinct portals activated hydraulically by a single gearbox. A series of entering/exiting and loading/unloading manoeuvres by the uphill and downhill train allowed the materials to be transferred.

All the manoeuvres were performed by the locomotive operators by remote control, avoiding at all times passage underneath suspended loads.

4.5 Dismantling the TBM and the Back-up

Like for the assembly, the disassembly also became a difficult and delicate operation because of the surrounding conditions, as well as the tight time constraints. In particular, the geological surveys performed on site had found the presence of a detritic sheet right in the area of the tunnel outlet, thereby making it necessary to build an exit trench about 60 metres in length and with a 21% slope, and preventing the creation of a suitable disassembly yard beside the area where the belt head structure was to be installed. In order to keep the work schedules – and thus the start of the belt – from being delayed even further, the decision was made to leave the yard free for the installations of the belt head structure, and to dismantle the TBM and the back-up in the slope directly from the excavated trench (see photo 12).

Photo 12

The need to dismantle the TBM in a 21% slope, the fact of having only about ten metres of space for the cranes to work, and the presence of the conveyor belt connected to the back-up made it absolutely necessary to produce a careful technical/executive study and to schedule the disassembly phases down to the minute. Explained in very simple terms, the process of extracting and disassembling the machine was as follows.

After the breakthrough, once the cutterhead was outside of the tunnel, two hydraulic jacks were installed up-slope of the trench (see photo 14), and towing ropes were laid and anchored to the cutterhead. Since technical reasons required the belt's provisional return station to be left 100 metres from the exit, the TBM, Back-up, and belt bloc had to be towed in the initial phase.

Photo 13

The working sequence required pushing the TBM by using the auxiliary cylinders (single-shielded mode) and simultaneously towing by using the hydraulic jack (see photo 14).

Photo 14

In the beginning, the thrust was acting on the whole ring. Then, once the final ring was installed, progress was made by pushing only against the invert.

When each 1.3 metre stroke was completed, the invert was set in place and anchored to the ground with a 1.5 metres long rock bolts.

During the invert installation phase, the entire weight of the system was held by the jack and by friction.

When the belt head had reached 100 metres from the tunnel exit, the belt was anchored with a clamp, and the back-up with a support structure. At this point, the belt could be disconnected from the back-up and the back-up from the TBM, and the towing of the TBM was completed up to the disassembly point where the various components have been hoisted by crane.

Once the TBM was disassembled with the aid of a winch instead of the hydraulic jack, the back-up platforms were towed one at a time to the point of crane operation.

5. GEOLOGICAL SURPRISES: CARSIC CAVITIES

The last section of the tunnel was marked by the expected compactness and integrity of the limestons formation called "Moltrasio limestone." As a result of the predicted very good quality of the rock mass, at design stage was decided to leave unlined, except for the invert segment, 850 metres within this section of the tunnel.

In December 2004, as the final rise was being neared, a decision was taken to modify the design indications and – in order to disperse any uncertainty that could have compromised safety during tunnelling – was decided to line the excavation for its entire length. The choice turned out to be a perfect one: in rather close succession, the TBM came across three mid-sized carsic cavities (see photo 15) (25 cubic metres, 60 cubic metres, and 30 cubic metres respectively), filled with wet clayey material. Moreover, the surrounding rock was also quite fractured, and this led to the release of blocks – some of considerable size – when the clayey mud came out. In all three cases, the TBM advance was halted and the cavity was filled with bi-component silicate resin. Before re-starting the excavation it was necessary to demolish some large blocks that were blocking the cutterhead. Works have been then resumed with great caution, by thrusting at only 50% of the normal thrust, always checking the cutterhead prior to each stroke. To get past the cavity, it was necessary to advance in single-shield mode, using the auxiliary cylinders and countering the thrust directly on the segments. The three cavities that were encountered were overcome by all means thanks to the versatility of the double-shield TBM, but above all, thanks to the experience and specialization of the personnel, which in these cases is the only true determining factor for a trouble-free and completely safe solution to the problem.

Photo 15

6. PRODUCTION

The considerable complexity of the project strongly conditioned production, especially given the productive potentials of the selected TBM, which never shown particular difficulties of penetration.
The conditioning factors were essentially the following:

- forced stoppages every 200 metres of tunnelling due to belt lengthening operations (about 3 months lost);
- transport system (special trains);
- the switching systems used (in a series, with no possibility of using Californian switches);
- slow-downs and stoppages due to the difficult and at times impossible management of belt slippage;
- miscellaneous belt malfunctions.

Upon completion of the tunnel, the production parameters may expressed as follows:

Maximum daily production:	*39 m/g;*
Average daily production:	*19,3 m/g;*
Maximum monthly production:	*702 m*

The production levels reached – given the tunnel alignment and the complex geometry in addition to the unavoidable local constrains – are to be considered particularly positive, thus demonstrating the soundness of the performance solutions and technologies employed.

7. CONCLUSIONS

The preliminary and supplementary geological investigations associated with the choice of a double shield TBM made it possible, despite the particularly complex geology, to reduce to a minimum the uncertainties during the construction phase and delays due to face and walls instabilities.
The technical adjustments made to optimize the running of the conveyor belt, such as the external “belt storage unit,” the car with return drum connected to the back-up, and the optimization of the production cycle using prototype trains in the steep slope sections and intermediate switching systems designed ad-hoc, made it possible to achieve and maintain over time levels of production of significance for proving the soundness of the performance solutions and technologies employed.