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Tunnels and Underground Cities: Engineering and Innovation meet Archaeology, Architecture and Art – Peila, Viggiani & Celestino (Eds)
© 2019 Taylor & Francis Group, London, ISBN 978-1-138-38865-9

The first huge pressurized ventilation system in the world, realized in Brenner, with heavy duty centrifugal fans

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ABSTRACT: For the first time in Europe, the installation of centrifugal fans for renewal of sanitary air makes its debut in an underground construction site, seeing the use of new heavy-duty machines.

When very high ventilation system performances are required, centrifugal fan steal the show to the more traditional solutions obtained by means of single and multiple stage axial fans. This is the case of the BTC Mules 2-3 worksite where the new ventilation system is required to cope with sanitary ventilation of the underground construction site with a total flow rate of 420 m^3/s and 6,000 Pa of total pressure and with total electric power of about 3.2 MW.

The system is required to guarantee air renewal for pollutants dilution produced by almost 10,000 kW of total power expected during underground operations and to guarantee the salubriousness of the air for the workers involved (200 people), along ca. 40 km of tunnels.

1 INTRODUCTION

Since the beginning of 2016 the BTC consortium, formed by Companies Astaldi, Ghella, PAC, Cogeis and Oberosler, has been involved in the construction of the longest underground railway link in the world: the Brenner Base Tunnel, which forms the central part of the Munich-Verona railway corridor.

The whole project consists of a straight railway tunnel, which reaches a length of about 55 km and connects Fortezza (Italy) to Innsbruck (Austria); next to Innsbruck, the tunnel will interconnect with the existing railway bypass and will therefore reach a total extension of about 64 km.

The tunnel configuration includes two main single-track tubes, which run parallel with a 70m span between each other through most of the track, and linked every 333 m by cross passages (Figure. 1).

Between the two main tunnels and driven 12 meters below, an exploratory tunnel will be excavated first. Its main purpose during the construction phase is to provide detailed information about the rock mass Furthermore, its location allows important logistic support during the construction of the main tunnel, for transportation of excavated material as well as that of construction material. During the operations, it will be essentially used for the drainage of the main tunnel.

The excavation process is divided into 2 blocks; the first one will be bored by n. 3 TBMs (n. 2 for the main tunnels and n. 1 for the exploratory tunnel, toward North). The second

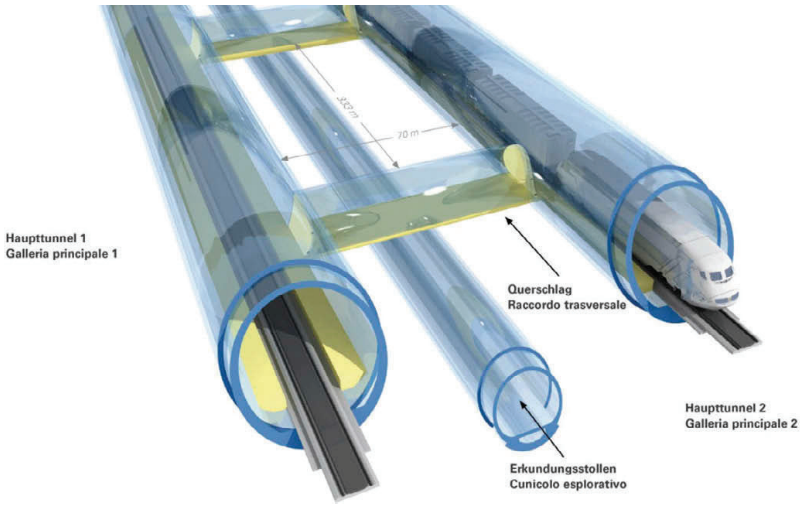

Figure 1. Brenner Basie Tunnel.

one will be bored with traditional method, including mainly drill & blast in the competent material and special drilling techniques in the faulty zones, toward South and in some areas toward North.

Company CIPA S.p.A. is currently handling most of the tunnel excavations activities in the lot named "Mules 2-3" with the French drilling partner Robodrill SA. These mainly consist of:

– Excavation and lining of the ADIT Tunnel at the Trens Emergency Stop and the Central Tunnel, with a total length of approx. 4,500 m;
– Excavation and lining of the Exploratory Tunnel by traditional method, with a total length of approx. 830 m;
– Excavation and lining of the Main Tunnel toward South, East tube and West tube in single track section, with a total length of approx. 7,320 m;
– Excavation and lining of the Main Tunnel toward South East tube and West tube in double track section, with a total length of approx. 2,590 m;
– Excavation and lining of 19 Connecting Side Tunnels linking the two main tubes, with a total length of approx. 900 m.

All the material excavated in traditional method by the subcontractors Cipa, Europea92 and LSI, runs from the central cavern up to the surface, sized by a crusher, by means of Marti Technick belt conveyors. The material is also divided in 3 different geological classes and moved according to needs in 2 different depony areas.

1.1 *Mules 2-3*

As already said the Mules 2-3 construction lot is the main part of the BBT track on the Italian side; in particular it is between the State border, to the North (km 32.0 + 88 East Reed) and the adjacent lot "The Isarco River underpass", to the South (km 54.0 + 15 East Bound Track). The works for this construction lot, the biggest in the Brenner base tunnel, has started on September 2016. The lot Mules 2-3, which value is about for 993 million euros, has been assigned to joint venture called BTC S.C.A.R.L. constituted by Astaldi S.p.A., Ghella S.p.A., Oberosler Cav Pietro S.R.L., Cogeis S.p.A. and PAC S.p.A. General lay out of Mules 2-3 lot is shown in Figure 2.

Complex excavation activities has to be conducted including: about 39.8 km for the line tunnels and about 14.8 km of exploratory tunnel, the emergency station in Trens together with the related adit tunnel, and the cross passages tunnels, which will connect the main tunnel every 333 meters. By the end of 2023, 65 kilometers of tunnels within this construction lot will be excavated. Once finished "Mules 2-3", all the Italian side underground works will be completed.

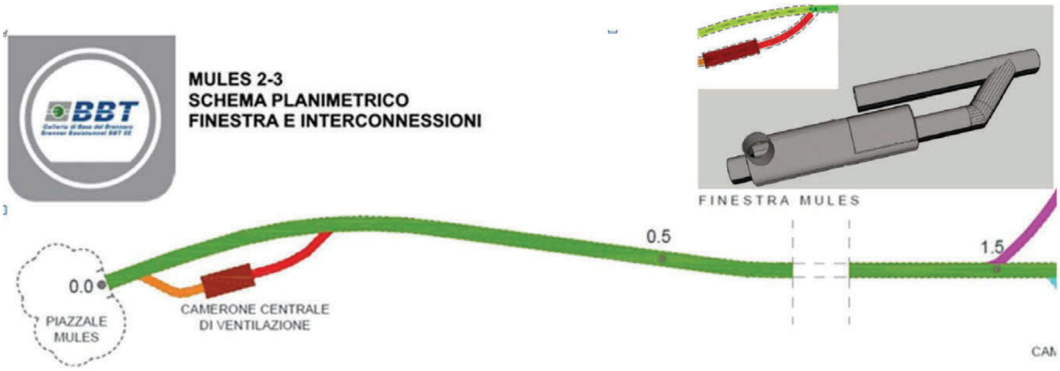

Figure 2. Mules 2-3 plan view.

2 GEOLOGICAL CONDITIONS

As anticipated, the Brenner Base Tunnel is the high-speed rail link between Italy and Austria and therefore establishes a connection with North East Europe. It consists in a system of tunnels, which include two single-track tunnels, a service/exploratory tunnel that runs 12 m below them and mostly parallel to the two main tunnels, bypasses between the two main tunnels placed every 333 m, and 3 emergency stop stations located roughly 20 km apart from each other. The bypasses and the emergency stops are the heart of the safety system for the operational phase of this line.

Average Overburden is, between 900 and 1.000 m, with the highest one about 1.800 m at the border between Italy and Austria.

The excavation will be driven through various geological formations forming the eastern Alpine Area. Most of these are metamorphic rocks, consisting of Phyllites (22%), Schist (Carbonate Schist and Phyllite Schist, 41%) and Gneiss of various origin (14%). In addition, there are important amounts of plutonic rock (Brixen Granite and Tonalite, 14%) and rocks with various degrees of metamorphism, such as marble (9%).

Among the tectonic structures in Italy, we find the above mentioned Periadriatic Fault. As mentioned, the unknown characteristics of the rock masses along this stretch determined the necessity of excavating the exploratory tunnel long before the main tunnels, in order to allow the identification of lithological sequences of the various types of rock mass within this heavily tectonized area, as well as a detailed study of their responses to excavation. These analysis were subsequently used to adjust the consolidation and support measures both for the exploratory and for the main tunnels. The excavation of the exploratory tunnel inside the Periadriatic Faults allowed to determine the actual sequence of lithologies within this area.

A short geological description is necessary in order to understand the chosen excavation process, the mucking out system and the subsequent fresh air need. This is divided in mechanized tunnelling for the good and competent rock types along the exploratory and the main tunnels toward North, D&B for a limited distance toward South (2-3 km) and in some minor

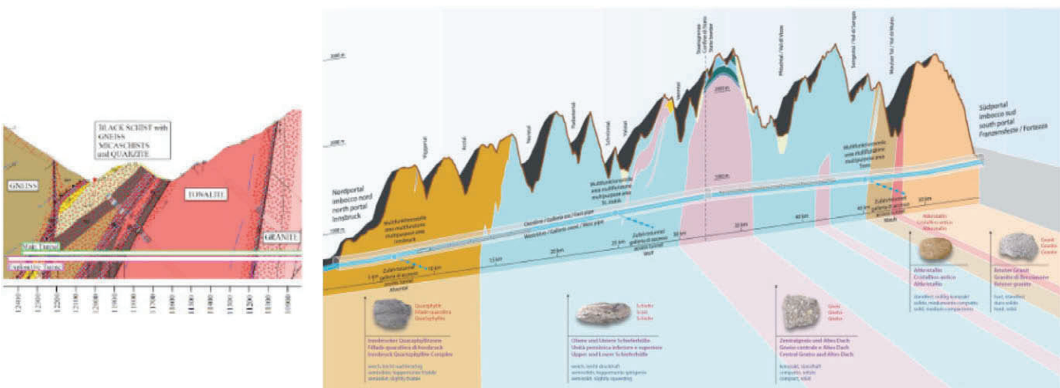

Figure 3. Geological distribution.

short tunnels as well as several bypasses and traditional method (mainly self drilling anchors protection umbrellas and hammer excavation) in the faulty areas. It is also interesting to understand difficulties related to the excavation in the hard granite as well the related problems linked to the abnormal wear and tear due to high abrasivity.

A summary of the encountered rock sequences is illustrated with Figure 2.

3 THE BELT IDEA

The conveyor belt system allows a straightforward and efficient mean of transportation for material going both in and out from the underground rock crusher, and in and out from the underground concrete batching plants. It evolves while the project is carrying out and is gradually implemented in accordance to the work's progress.

This system has been chosen not only for its efficiency in general but also, and may be mainly, to lower down fresh air need along the full project.

The conveyor system has been rationalized during the tender phase maintaining its high potential, flexibility and capacity. The differentiation of the two belts in Aica (belt 1 and belt 2) allow each single band to be allocated with a certain type of material; therefore belt 1 is for material A (good material for concrete) and belt 2 is for material B+C (semi-good and not concrete-accepted material). The differentiated configuration avoids alternating different material types with temporary stocking buffer on the same conveyor. However, the system provides the possibility to switch the material types in Aica according to necessities. This kind of realization allows an easier management of the whole system.

Such works may be identified in three major phases. This short report is aimed to describe the choices taken within the Construction Project and to list them congruently to the time-related phases.

Without taking into consideration the specific calculations regarding the Executive Work Program's Space-Time Diagram, the 4 major phases may be described as follows:

- Phase 1: excavation of the Exploratory Tunnel (CE) with the conventional excavation method and the TBM assembly chamber; realization of the excavation of the first part of the North Line Tunnels (GLN) by traditional system and excavation of the South Line Tunnels always by traditional method (done by Cipa S.p.A. with its Drilling Partner Robodrill SA);
- Phase 2: continuation of the activities following the previous phase; realization of "in cavern" assembly areas for the two TBMs, which will excavate the Line Tunnels (toward North), excavation prosecution of the South Line Tunnels with drill & blast system (GLS) and realization of the mechanized excavation of the CE Northwards.

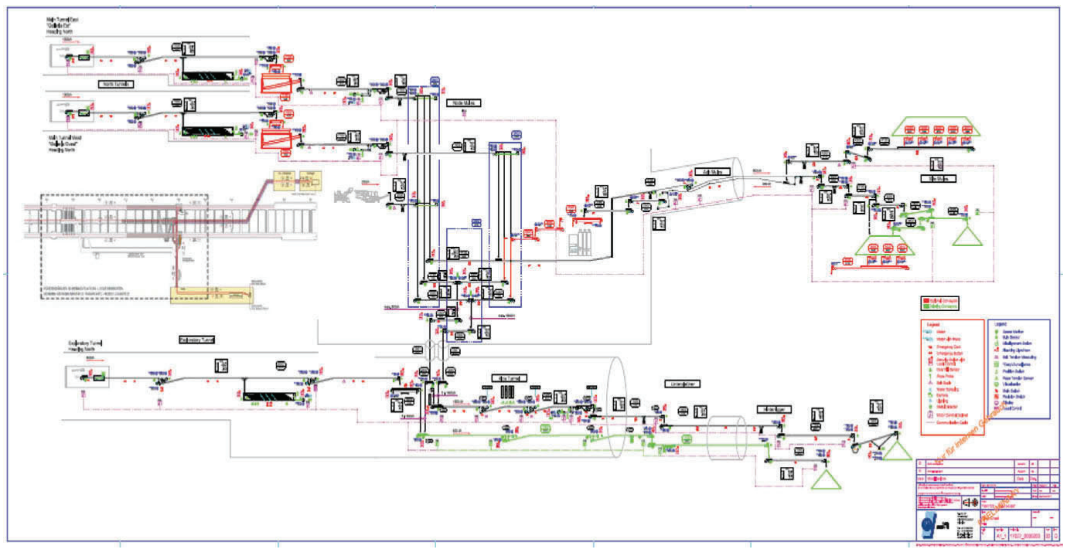

Figure 4. Belt lay out with cavern zoom (center left).

Figure 5. Mules configuration and A22 highway transfer belt to Genauen 2 intermediate waste dump.

– Phase 3: prosecution of the precedent activities, excavation of the North Line by mechanized tunnelling (GLN) and subsequent finishing job site works.
– Phase 4: main TBM tunnels secondary final lining. This also represents a complex activity, which will take more than 1 year. A part of this job will be anticipated during TBM excavation, deviating logistic and traffic from one tube to the parallel one. The phases are integrated and shown in the complex lay out indicated in Figure 3.

All belts generally are connected to the five excavation fronts with the Logistic Knot (N). The system is flexible, but actually in the current phase belts are directly used only for the North bound tunnels (3 TBMs). For the South bound (conventional excavation) the material is transported by dump truck up to the logistic Knot, where after resizing (by the crushing plant housed underground within the cavern) it is transferred and transported by belt conveyor system. After that, from Knot N:

– Material type A is carried towards the jobsites Mules and Genauen 2 (depony area reached by a 180m long bridge belt conveyor – 300 ton/h – which crosses the A22 highway, the Isarco river, the National road S.S. 12 and the existing railway line, Figure 5), it is stocked and/or crushed outside and/or transported back to the underground batching plant, in order to provide D&B tunnels' primary and secondary lining.
– Material type A/B+C is transported to Hinterrigger jobsite and it is used to produce the precast elements and pea-gravel for the TBM's back filling. Concrete segments and pea gravel will be then transported back into the tunnel with a dedicated rolling stock through the Aica Tunnel.

4 THE VENTILATION IDEA USING HEAVY DUTY & HIGH PERFORMANCE CENTRIFUGAL FANS

For the first time in Europe it makes its debut in an underground construction site for the construction of a railway infrastructure, the installation of centrifugal fans for the supply of fresh air to the excavation fronts. The debut could not be more striking of such a new heavy-duty machine, designed and built by CBI Industrie S.p.A., for the key lot of the new Brenner Base Tunnel.

When a very high-performance ventilation scheme is required the centrifugal fan can steal the spotlights to the most conventional solutions such as the single and multiple stage axial fans. This is the case of the mules 2-3 jobsite, where the new ventilation system is required to cope with the renewal of the underground breathing air through a total flow of 420 m^3/s at a pressure of 6,000 Pa with and total installed power of approx. 3.2 MW.

4.1 *Main Ventilation System – Supply of fresh air to the underground working areas*

The ventilation system requires, during the operation, to assure the safest environmental conditions, clearly indicated by the HS authority, and in particular to dilute the concentration of harmful substances in the entire underground area.

For the Mules 2-3 construction lot, the ventilation system is required to guarantee air renewal and the dilution of the pollutants produced by the almost 10,000 kW of power produced by the underground machineries thus in order to guarantee the breathiness of the air for the workers involved (approx. 200 units).

As per the following table a list of tunnel machineries foreseen to be used in the project.

Id.	Type of Machinery	Type of Engine (Diesel/Electric)	Installed power (kW)
1	Waterproofing Gantry	E	20
2	Re-bar Gantry	E	20
3	Service Car 4WD	D	70
4	Concrete batching Plant	E	150
5	Concrete batching Plant	E	150
6	Concrete Pump	D	70
7	Jumbo Drilling Rig (BIG)	D	70
8	Jumbo Drilling Rig (SMALL)	D	75
9	Stone Crusher	E	200
10	Dumptruck (BIG)	D	300
11	Concrete Truck Mixer	D	240
12	Belt Conveyor	E	800
13	Forkliftt	D	80
14	Service Car 4WD	D	100
15	Gantry Crane (BIG)	D	80
16	Gantry Crane (SMALL)	D	60
17	Minibus	D	80
18	Grout Injection Plant	E	10
19	Overhead Gantry	E	50
20	Exploratory Tunnel - Service Gantry	E	1350
21	Northbound Tunnel – Service Gantry	E	1500
22	Southbound Tunnel – Service Gantry	E	1500
23	Wheel Loader (BIG)	E	200
24	Wheel Loader (SMALL)	E	120
25	Tunnel Formwork	E	50
26	Tunnel Invert Formwork	E	20
27	Shotcrete	D	80
28	Exploratory Tunnel - TBM	E	4100
29	Northbound Tunnel – TBM	E	4600
29	Southbound Tunnel – TBM	E	4600
30	Dump Truck	D	130
31	Crawler Excavator	D	130
32	Underground Workshop	E	200
33	Service Train - Cross Passages (Finishing)	D	155
34	Service Train - Cross Passages (Excavation)	D	155
35	Service Train – Muck Transport	D	155
36	Service Train – Segments' Transport	D	273
37	Service Train – Segments' Transport	E	273
39	Service Train – Personnel Transport	E	50
40	Dump Truck	E	50
41	Booster	D	273

The air produced by the Main Ventilation Unit is provided to the working areas by means of a series of flexible ventilation ducts installed along the main adit tunnel to the exchange cavern (Figure 6) and from there branch out into six header feeding the six excavation fronts.

The design criteria for the air demand calculation are:

- supply unitary flow rate for workers: ≥ 3 m^3/min/person
- supply unitary flow rate for pollutants dilution: ≥ 4 m^3/min/kW
- air velocity inside tunnel: ≥ 0.30 m/s (maximum admissible value 5.0 m/s)
- air velocity inside tunnel (in presence of potential CH_4): ≥ 0.50 m/s

Figure 6. Ventilation ducts in the Mules adit.

4.2 *The ventilation station and the service plenum*

The ventilation station is installed in a dedicated recess/room realized along the adit tunnel, where no. 4 centrifugal fans are installed sucking fresh air provide by a ventilation shaft ended up into the chamber.

The need to interface the no. 4 centrifugal fans to the no. 3 flexible ventilation ducts blowing air along the adit tunnel, has determined the realization of a “tunnel plenum” (Figure 7). The plenum has been realized installing bulkheads, along the excavated chamber, between the ventilation units and the intersection with the adit tunnel.

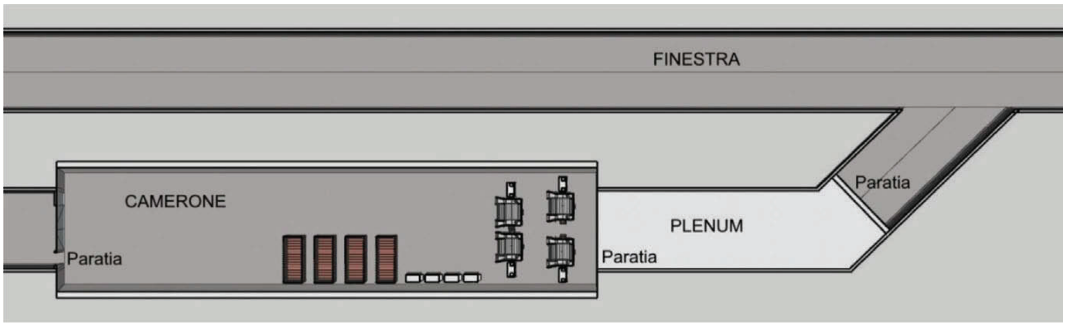

Figure 7. Plan view of the ventilation chamber.

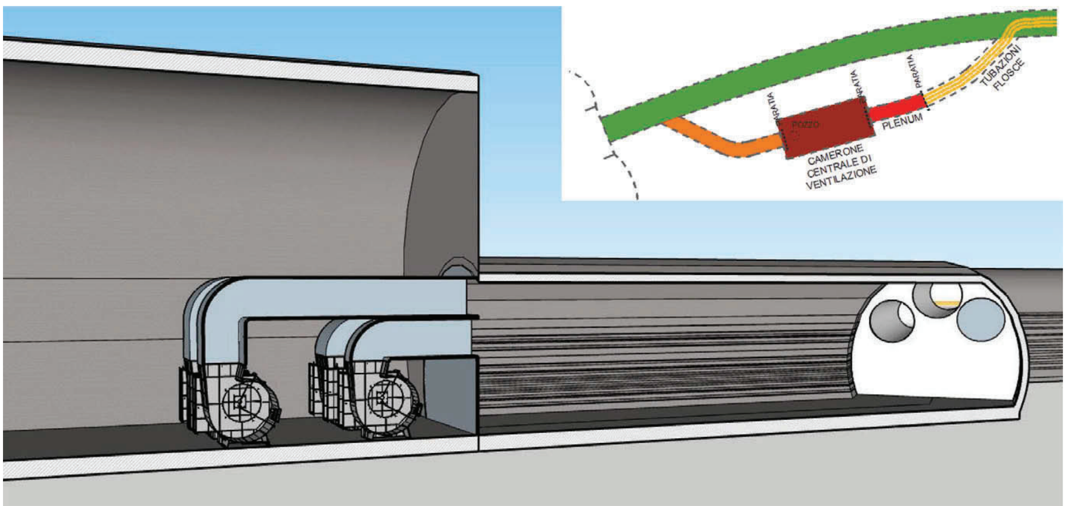

Figure 8. Typical installation lay-out of ventilation ducts interfaced to a ventilation plenum.

On the bulkhead interfacing the fans no. 4 diffusers are installed together with no. 4 ON/OFF dampers; on the opposite bulkhead no. 3 Dapò dampers are installed thus in order to interface the no. 3 flexible ventilation ducts (Figure 8).

4.3 *Ventilation Fans*

The ventilation system is therefore provided with no. 4 high-performance centrifugal fans of the CH series with a 10-blade aerodynamic impeller able to guarantee overall the nominal performances required by the project (Figure 9). The fans are supplied @ 400V-3ph-50Hz, equipped with a power supply/control unit complete with VFD.

The provided solution allows to achieve:

– The modularity of the loads and the ventilation capacities.
– The control of the machines performances during the flow throttling phases (considered for about 90% of the operating time).
– The system availability assuring continuous supply of fresh air to the excavation fronts of even in case of machines failure or machines stopped for maintenance. In comparison to a single machine linked to the related ventilation ducts, the presence of a ventilation plenum assure simultaneous distribution of the flow rate through the three ventilation duct lines.

The use of centrifugal fans therefore allows the following benefits:

– Maximizing the operating efficiency.
– Minimizing the installed power.
– Optimize energy consumption.

Only the use of this type of machine, in fact, allows to obtain, with the nominal performances required, always exceeding 84% with maximum peaks close to 90% (89% in the conditions of partial loading), thus assuring for the overall operation time to minimize the power consumption and maximize the energy requirements therefore the direct operating costs.

Table reported in Figure 10 is just a saving estimation related to only 3 working phases on ca. 20 on which the job site is foreseen to move in the years along.

The reliability and experience gained by CBI in the design, manufacturing, supply and servicing (Figure 11) of such heavy duty fans has allowed BTC S.C.A.R.L. to sign an agreement for a comprehensive field service including the guarantee extension of the supplied machines for the whole duration of the project (7 years!). The presence of a well-organized field service at less than 300 km far away from the jobsite, has undoubtedly comforted the Customer in his choice.

4.4 *Adjusting the flow rate to the excavation fronts*

Each of the three ventilation ducts installed along the adit tunnel (Figure 12), once reached the logistic cavern, branches off to the provide fresh air the 6 excavation fronts, by means of different sized flex ducts and steel distribution boxes.

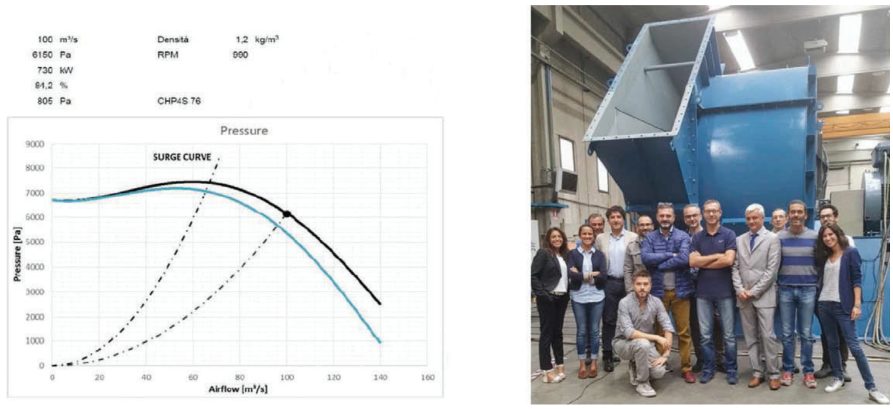

Figure 9. Curve performance example and FAT of the first Centrifugal Fan CH4S 76 (SIS7).

		PROJECT DATA				PROJECT HYPOTHESIES			SOLUTION WITH 4 CENTRIFUGAL FANS					SAVING	
	Machine	Phase duration	Total working hours (3 shifts, 24 h)	Total air flow	Project prevalece VentSim (total pressure)	Fan total efficiency	Electric energy (as per project = 0,82)	Electric energy cost (calculated at 0,15 €/kWh)	Fans flow	Fans pressure	Effective efficiency in the working point	Electric energy consumption	Electric energy consumption cost (calculated at 0,15 €/kWh)	Saving with the solution offered	Saving in money (calculated at 0,15 €/kWh)
Phases	Description	GG	[h]	[m3/s]	[Pa]	[-]	[kWh]	[€]	[m3/s]	[Pa]	[-]	[kWh]	[€]	[kWh]	[€]
Phase 10	GLN and GLES traditional excavation, GLN lining, TBM CE and GLOS excavation	120,0	2.880	312,7	5.821	0,82	7.102.492	1.065.373,8	314	5.966	0,886	6.765.956	1.014.893,4	336.536	50.480,4
Phase 15	GA traditional excavation, GA lining, TBM CE and GLN excavation	169,0	4.056	351,3	5.357	0,82	10.342.925	1.551.438,7	361	5.491	0,869	10.272.055	1.540.808,2	70.870	10.630,5
Phase 20	GLN, CE, CT of FdE lining	168,0	4.032	299,6	4.198	0,82	6.870.516	1.030.577,4	305	4.203	0,863	6.650.305	997.545,8	220.211	33.031,6
													TOTALE	627.617	94.143

Figure 10. Energy saving estimation in function of 3 working scenario phases.

Figure 11. Fans installation phase.

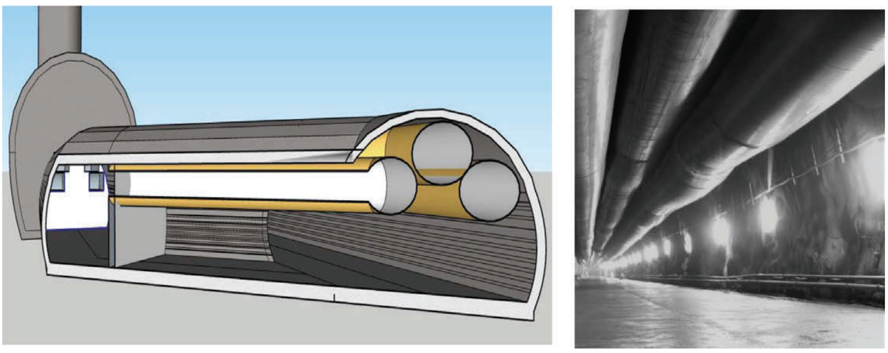

Figure 12. Flex ducts lay out after the plenum.

The flow rate adjustment the no. 6 ventilation branches is provided by motorized regulating dampers (2,000 x 2,000 mm and 2,500 x 2,500 mm) equipped with of flow/pressure control units.

In order to guarantee the full functionality of the system, the regulation system is integrated by a series of differential pressure sensors thus to measure the static and total pressure of each

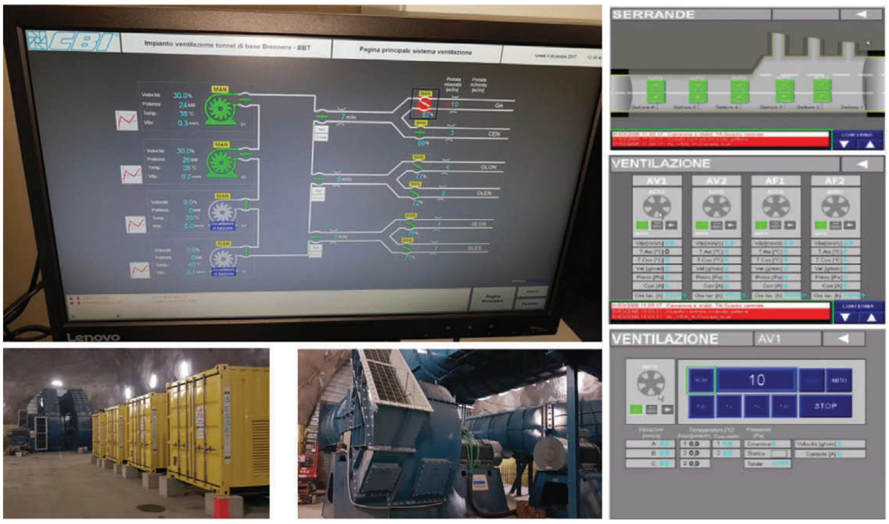

Figure 13. PLC integrated system with the ventilation plant.

fan downstream of each Dapò damper and the additional six pressure sensors upstream of each regulating damper. The complex centralized control system therefore provides a comprehensive operator interface able to constantly monitor the operating parameters of the fans.

Of course an integrated PLC system is controlling the full system, launching data and orders from a control cabinet (Figure 13).

5 CONCLUSION

The installation of the powerful Heavy Duty Fans has allowed ventilation of a very complex construction site ensuring ventilation modularity (adaptability to the process requirements) and combining high performances and operating efficiency.

Together with the continuity and reliability of operation, the HDF system ensures consistent energy saving without giving up the safety and the healthiness of the work areas.

ACKNOWLEDGMENT

All the BTC Team must be acknowledged for the hard and professional work done together, starting from feasibility study to the contractual and supply set-up: G. Frattini, S. Citarei, M. Ferroni, M. Secondulfo, A. Caffaro, R. Paolini, G. Vozza.

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