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

Moving material with belt conveyors in urban environment and for long tunnel construction in Italy: Metro Catania, Scilla's shaft, A1 highway and Brenner Base Tunnel

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ABSTRACT: Mucking out automatic systems have been nowadays widely exploited in practically all mechanized tunnelling projects. This mostly occurs due to the improvement of the related technologies that solve complex logistic-related problems, but also to the environment, safety, energetic aspects, CO2 emission, manpower optimization. Also Owners have already been specifying such systems in their tender documents as Brenner alpine tunnel, Turin-Lyon, Gothard, Loetschbeg. The paper describes a particular case in a urban contest which is the Catania Metro. Therefore, starting from little capacity and short tunnels we will arrive to huge diameter TBMs, such as the 16m diameter in A1 highway, up to BTC-Brenner Mules, where about 80 km of very complicate systems are able to handle various excavation front faces.

1 WHY TO USE BELT CONVEYORS?

A. Answering to this question is not complicated, at all...
B. In nearly all mining procedures, conveyor belts (Fig. 1) are especially necessary to limits movement costs (in terms of incidence reduction per ton of produced prime material) of excavated material toward the plant which is able to process it. Cost reduction is a combination of various parameters but, although this is a primary reason to develop such a technology, it is not the only one. There is a list of positive aspects in the application of this method, also projected in the tunneling world, in comparison with classical systems of transportation on wheeled vehicles. Here is a summarized list:

Figure 1. Belt conveyor solution to move material out from a trench.

C. Environment and safety: limitation of the environmental impact of the entire production process (CO2!), limitation of noise, elimination of dust production, more safety on the TBM concerning material management through an intrinsically extremely reliable system, general increase of safety parameters to prevent road accidents along the path to the landfill and pure presence of electric engines and exclusion of endothermic engines.
D. Energy: considerable energy saving in comparison with gas oil consumption and dimensioning and consumption saving for the ventilation implant.
E. Work cycle and manpower: the construction mucking system is continuous and is therefore available at any moment, overall less workforce engagement (including management such as cafeteria, housing, etc.) and more flexibility for work cycles (less employees and use of less technicians as opposed to many drivers).
F. Benefits related to the use of TBM: material excavated from the TBM is continuously moved in the tunnel and/or from the excavation shaft, no necessity of a long back-up to load the whole quantity of a complete stroke on the mucking train, absence of a wagons rollover system at the portal tunnel, no interference on the road between vehicles going out (mucked material) and in (segment transportation, injection material and personnel), no auto-repair garage for assistance and maintenance of the locomotors, no tankers or re-fueling plants, optimization and minimization of the spare part area and fewer personnel to handle the muck as a whole (drivers, mechanics, maintainers, safety systems inspectors, etc.).
G. Infrastructures: limitation of measures on the streets (repaving, signalizing, traffic lights, etc.) and less disturbance to the collateral infrastructures (urban, provincial and highway streets).
H. Therefore, the prejudice according to which a conveyor belt implant's costs are too high is unreasonable. To consider the elements mentioned above in the right way, is enough to evaluate the benefits of choosing this solution.
I. There are several examples of standard, complex or peculiar jobsites, in which applying such technology resulted in a successful job.

2 WHAT CHARACTERIZES A CONVEYOR?

Various topics should be analyzed in the preliminary design phase and the main components should be chosen accordingly, as:

- Product that occurs transportation
- Route, slopes, misalignments, …
- Capacity
- Cleaning (the cleaning of the belt is a major element in the design of the conveyors. Scrapers generally ensure this particular one with carburized blades of subjacent or tangential type. Turning systems usually serve on long conveyors).
- Motorization
- Belt tension
- Belt type
- Scraper
- Drive unit
- Feeding corridor
- Idlers/rollers (the idlers are the metal supports of the rollers and can be equipped with 2, 3, 4 or 5 rollers according, to needs; its lubrication is lifelong and its diameter is generally of 89, 133 or 159 mm. The load of products, idler spacing, and belt speed determine the rollers).
- Pulleys

The product which need to be handled has to be analyzed for it physical and chemical characteristics as: density, corrosive, powder (as cement), round (as aggregates), abrasive, liquid (muds), dimension (0 – 1000 mm), sticking, cutting, explosive, dangerous, …

The environment of the conveyor is also important (inside, outside, moisture, dusty, etc.).

The conveyor installation (functional lay out) is mostly important for the following:

- The calculation of power
- The installation of equipment of the conveyor and particularly the tensioning system

The conveyor is equipped with a tension system to:

- Allow the transmission of the power between the drive pulley and the belt
- Absorb the belt's length differences, caused by the elastic lengthening of the belt

There are three principal devices of belt tensioning:

- Tension (with screws or hydraulic) for conveyors of short distances between centres.
- Automatic tension with counterweight as a dancer, for higher distances between centres.
- Tension by capstan for small overall dimensions and high distances between centres.

The type of handled product will determine the width, speed and belt's coating.

The characteristics of conveying belts are mainly the type of carcass, of coating and structure elements.

There are three types of carcasses:

- Belts with metal carcass (Steel Cord), composed of steel wire ropes
- The multiple belt textile, equipped with various fabric folds (cotton, polyester, polyamide, aramid)
- The monopoly-belt textile, a carcass «mono-fold» of polyester or polyamide

The coating is the part of the belt in contact with the products. This can be: anti-abrasive, anti-heat, cold-resistant, anti-fat, anti-static, not easily flammable, impact-resistant, anti-clogging, . . .

Boring a tunnel is a specific application for belt conveyors, because their characteristics evolve as the boring goes on; therefore, a simultaneous extension of the belt conveyor is necessary.

There are two methods to bore a tunnel and two possibilities to realize the lengthening.

- If the tunnel is traditionally bored with explosive or road header, the belt conveyor generally extends per strokes, from 50 to 200 meters. The return pulley later usually assembles onto a structure equipped with skids, in order to translate it easily as the new structure has to erect on this side of the belt conveyor.
- If the tunnel is bored using a tunnel-boring machine (TBM), then the belt conveyor could extend continuously while the TBM progresses, without stop. In this case, the installation of a special frame elongation station onto the TBM's trailers is necessary, as well as the installation of a belt storage in the drive unit area.

In both cases, it is necessary to dimension the belt conveyor, taking into account the whole specificities encountered along the tunnel route, such as horizontal or vertical curves, slopes, etc.

Two types of belt storage are existing: horizontal or vertical; the vertical model is frequently useful for the city jobsites with little available space.

Before covering Italian experiences, we will describe an incredible job site in China, just to demonstrate the potential of the system on a large scale.

3 JINPING II – THE MOST DARING CONVEYOR BELT PROJECT EVER REALIZED

The Yalong River is one of the main tributaries of the Yangtze River and is located South-West from the Sichuan province. It is about 1600 km long with a 2800 m difference in level along several, very deep canyons. The Jinping II central will exploit along 120 km and generate 4800 MW.

The whole plant, with a huge underground power room, includes the realization of 4 pressurized tunnels, about 17 km long and with a 12,4 m diameter, also considered a drainage tunnel (about 6m diameter) running parallel to the other conducts, because these configuration is strongly karstic.

Figure 2. Complicate in-out lay out and interaction with the miner's buildings.

Figure 3. Cavern intersection and overland installation.

3 TBMs and 2 D&B equipped fronts produced about 20 million tons of waste material; conveyor belts moved and handled such quantities.

The power of the belt behind the TBM, in adit no. 3 for example, is in total 2800 kW, with an 1800 t/h output. This probably is one of the most high-performing installations ever made in the world, just overtaken from the Brenner-Mules one. This system must grant a TBM excavation productivity of 600 m each month.

However, the external belt system represents the true peculiarity of the whole system. It transports material excavated from the portal area to the terminal landfill and it is about 6200 m long. The total capacity established is 5600 t/h. Furthermore, the plant can work in reverse transportation for concrete aggregates with a capacity of 600 t/h.

The excessive muck serves to fill a lateral valley, which is at a height of about 300 m, and it is approximately 1 km long.

The challenge for this implant consisted of the rough terrain, the necessity of interaction not only with the "wild nature", but also with a settlement build for workers, which was sort of a small town (Fig. 2), together with a high capacity and the obligation to work without intermediate controls.

The whole structure inside the tunnel is suspended on the roof because of a clear project request which did not include installations that were fix on the ground, in order to leave the floor completely free to allow passage of vehicles and railways.

In order to realize a track compatible with the plant on a steep, mountainous land, the conveyor system was fundamentally elevated (Fig. 3). It is mainly composed of bridges with a 48 m span. In addition, it was necessary to create four bridges with spans between 62 and 200 m and a short tunnel to avoid a particularly tortuous track. Two of the bridges are de-signed in a suspended version, because of the width of the respective spans.

Various integrated systems composed of different elements such as transfer towers, intermediate belts, intermediate stocking volumes placed at a 60m height completed the whole installation . . .

4 SCILLA'S TUNNEL AND MELIA'S SHAFT, CIPA S.P.A

The project consists of a sub-horizontal, 2842 m long tunnel, blind bore excavation and a vertical shaft approximately 300 m deep (Fig. 4). This work's function is to receive certain electrical submarine high tension cables from Sicily.

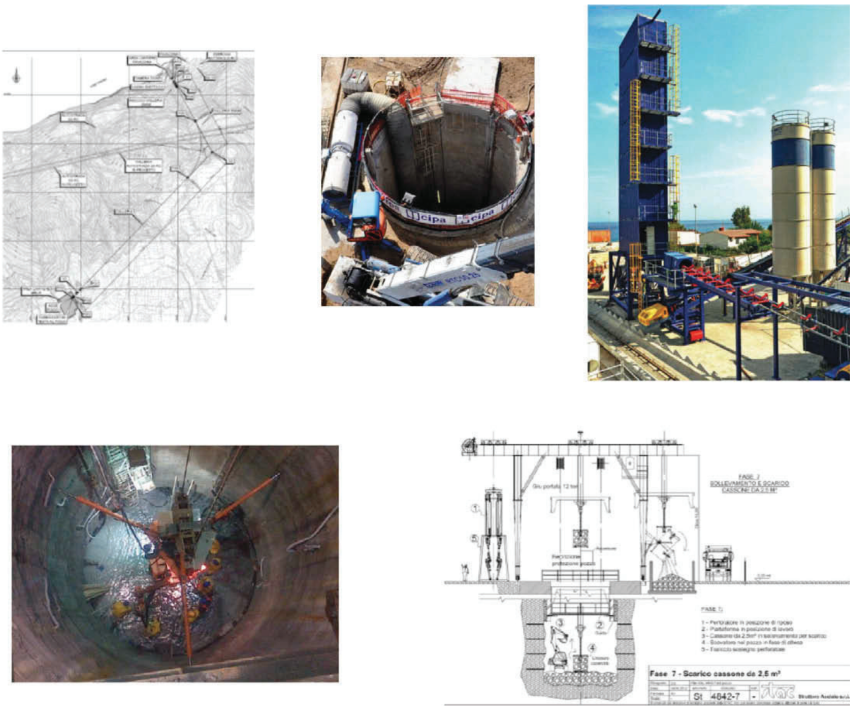

Figure 4. Some views and shaft installation sketch.

The TBM's diameter is 4100 mm, prepared to excavate in highly fractured, competent gneiss, in single and double shielded mode.

There were four main peculiarities of the disposal system:

1. A continuous plant, which is able to follow the TBM excavation even with elevated gradients and especially the limited altimeter-plan curve radius.
2. A compact plant in order to work in a 3,6 m internal diameter tunnel.
3. A regenerative plant which (13% slope), with no influence whatsoever on the electric consumption, is able to produce EE to be "pumped" in line.
4. A vertical belt storage, which limits space in plant as much as possible. The launching tunnel is located on a very nice beach!

We must mention the "vertical wise" excavation, record in Europe, when explaining this project. It is a 300m deep shaft with an excavation diameter of approximately 7 m.

The excavation of the first 80 m consisted of weak-consolidated sand, which foresaw "soil improvement" operations through jet grouting, reinforced with steel tubes.

After this stretch, the excavation was systematic "drill & blast", with different specifically designed equipment for this process.

The drilling machine is equipped with two booms, with a portal crane to support it. Appropriate stabilizers granted a stable and safe work cycle.

The lifting system is able to move longitudinally and transversally on appropriate rails. It bears a 4 rope winch to lift the working platform and a double rope to lift loads (muck and construction material).

The platform's central area can be subject to enlargement in order to allow the passage of necessary excavation and consolidation tools at the bottom of the shaft.

The designed system also includes a lift and an elevator for the transportation of personnel and various materials.

In order to handle the presence of copious water there are several intermediate niches, which are used to contain tanks and relaunching pumps.

In order to realize the final lining, an auto lifting platform started at the bottom of the shaft. During this operation, 3 pumps (5 l/s with a 300 m prevalence) have been installed with pipes inserted in the lining.

5 METRO CATANIA: HORIZONTAL AND VERTICAL SYSTEM ABLE TO MOVE DIF-FERENT KINDS OF GEOLOGICAL MATERIAL (VOLCANIC ROCK AND CLAY)

This is the extension of the railway on Catania's underground route from F.S. Main Station to the Airport – "Stesicoro-Airport route 1st Lot". Ravenna based CMC has acquired the job in current final execution phase.

It was necessary to realize an appropriate system to handle different rock types during excavation phase in this jobsite (Fig. 5). These types include stones and clays. Apposite additives and foaming handle these rocks in order to allow TBM-EPB mode excavations.

The major complexity is the material management integrated system. The geology has many different characteristics (volcanic rocks, clay, sand, fractured and weak material) and it has been necessary design a particular system able to efficient work especially during the vertical transportation phase.

The system composition is as follows:

1. Tunnel belt with belt storage (100): length 2500 m, width 1000 mm, type steel cord (EN 14793, Class A), capacity 800 t/h, speed 3 m/s. The system is compatible with the one installed on the Herrenknecht S454 machine, property of CMC, and equipped with emergency stop every 250 m (included design and construction of the structures meant for wagon no. 5 and 6).
2. General Characteristics of Tunnel Belt Storage: capacity 500 m, type horizontal with n. 14 return stations, length 62 m, width 2,4 m, height 4,5 m.

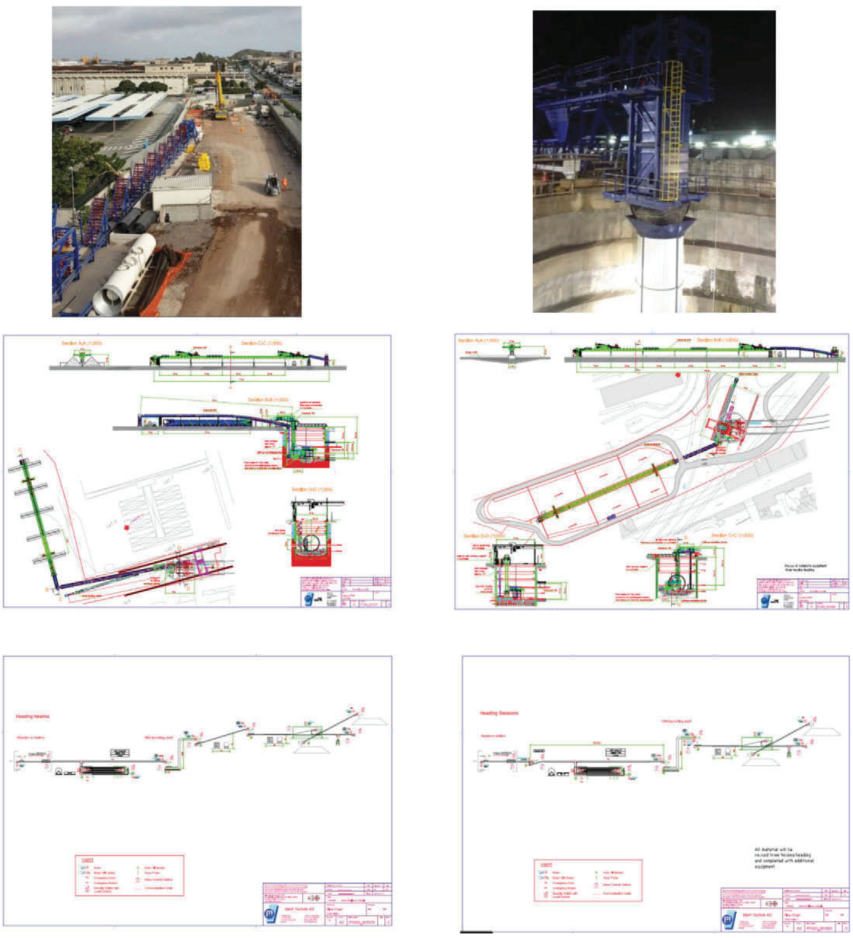

Figure 5. Installation site and system lay out.

3. Vertical belt (Elevator 200: height 27,2 m, capacity 800 ton/h, bucket belt type XDE-SC 1000/6+2, belt width 1400 mm, presence of an automatic cleaning system (wash box) including double pulley and small service belt.
4. Surface belt (300): length 94 m, structure width 2,3 m, belt width 1.000 mm, capacity 800 ton/h, speed 3 m/s, belt type EP – Textile 400/4+2 (DIN 22102, Y).

6 HIGHWAY A1 FLORENCE-BOLOGNA: HIGH PERFORMANCE BELT CONVEYORS IN THE BASIS, SPARVO AND ST. LUCIA - Ø 16 M - TUNNEL

The Variante di Valico (Crossing Variant) is the alternative way of the Apennine section of the Autostrada del Sole Milano-Napoli; it is a 62,5 km long route between Bologna and Florence. Traffic peaks of up to 90,000 vehicles per day of which about 24,000 are heavy vehicles, characterize this part of the A1 highway. These numbers make the old infrastructure unsuitable for the current needs of transport. The new project will overcome the Apennines at a lower altitude than the previous track, with a path full of viaducts and tunnels that will make the new highway more modern and efficient.

The conventional method excavated Base Tunnel's section measures about 180 m^2. It is approximately 8500 m long and features two tubes. It has been realized by Company Todini Spa.

The belt, supplied and installed in the central portal by Marti Technik, was 800 mm wide with a minimum radius of 215 m. It could carry 500 tons of material per hour for a power demand of 450 kW. It moved a total of about 2 million tons of muck.

The muck feeds into a jaw crusher and later moves through an encapsulated belt conveyor with bridges for about 1.4 km and then reaches a temporary storage area with a wheeled movable stacker.

The plant allowed avoiding heavy traffic, noise, dust and pollution around the local areas.

The Sparvo tunnel (Fig. 6), realized by Company Toto S.p.A., is 2 x 2.6 km long and its excavation occurred with a record 15.6 m diameter TBM; at that time, it used to be the largest in the world. The excavated material is composed of sandstone and clay and presented different behaviors throughout the process.

A 1200 t/h Marti belt conveyor carried material for about 1,6 km and deposits it in the storage area through a special 315 m long tripper, which runs on rails. From here, trucks loaded with this muck transport it to a service area closed by the existing highway. The material was later discharge into a hopper of 30 m^3 capacity and reaches the final stock area by a 500 m belt conveyor crossing a regional road. The muck finally spreads out through an extensible belt in combination with a telescopic crawler stacker (Fig. 7).

The last challenge, presently still on going, is the St. Lucia tunnel, where Pavimental S.p.A. is using an EPB-TBM having the world record diameter of 16 m; it's excavating a 7,9 km tunnel.

The just installed plant has a conveying capacity max 2000 t/h, average 1750 t/h, with rock density (loose) of 1700 kg/m^3, it can handle lump size max 0-300 mm (as very exceptional case, only single lump L= max. 800 mm), 3 m/s speed.

Figure 6. The Sparvo Tunnel.

Figure 7. Special belt conveyor to spread out the muck.

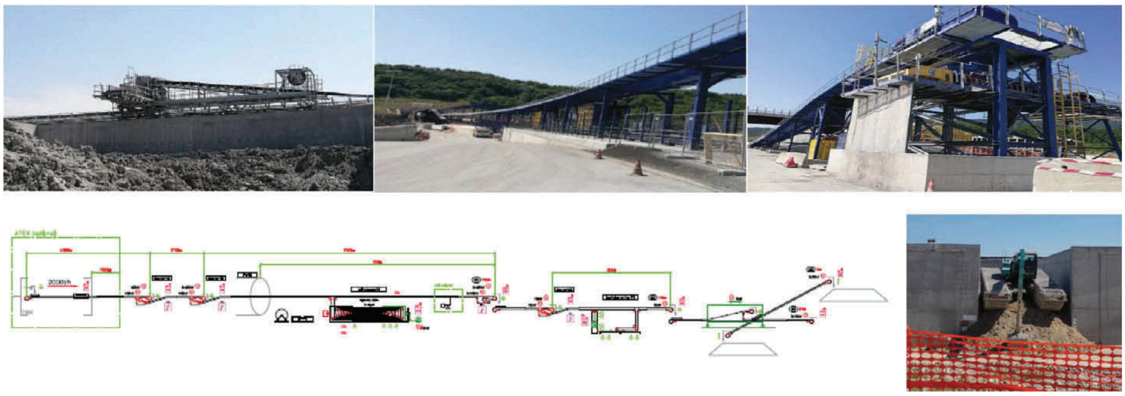

Figure 8. Tripper car, overland conveyor and general lay out.

The belt width is 1400 mm, only the TBM belt has ca. 4000 kW power installed. The belt storage has been designed to host 600 m of belt, in order to let the TBM run for 300 m before the new belt recharge,

The excavated material of the TBM is transported by TBM conveyor onto the tunnel conveyor. The area where the material has to be fed, the return and extension stations for the continuous conveyor extending, are on the back up system on the TBM. The tunnel conveyor is directly connected with the TBM via the return station and can be continuously extended without interrupting the tunnelling.

The drive station is approximately 300 m before the portal. At the drive station of the tunnel conveyor, the excavation material is conveyed on the external belt conveyor which transports the muck to the dump conveyor.

A long overland conveyor (ca. 2 km), with curves, is bringing the material up to the dump conveyor where a tripper of 300 m length is filling the huge prefabricated dumping area. The tripper, having a belt width of 1.600 mm, is of reversible type and have a length of 12 m (Fig. 8).

There is no explosive atmosphere during regular operation expected - if such a case would happen, then only seldom and temporary. It has been therefore defined zone 2 according to ATEX 1000 m behind TBM, so the system is in a sort of evolving ATEX con-figuration while the TBM is excavating.

7 BTC-BRENNER BASIS TUNNEL

The Companies Astaldi, Ghella, PAC, Cogeis and Obersosler form BTC Consortium. Since early 2017, BTC has been involved in the construction of what will become the longest underground railway link in the world: the Brenner Base Tunnel, which is the central part of the Munich-Verona railway corridor.

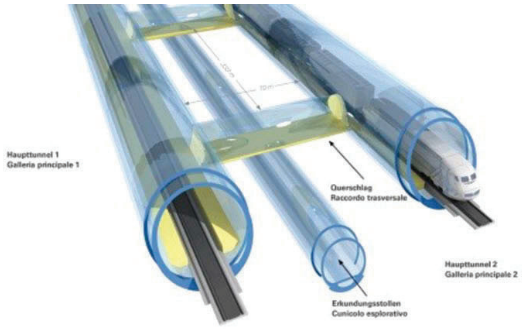

Figure 9. Lay out of the Brenner Base Tunnel: main tunnels and the exploration tunnel.

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

The tunnel configuration includes two main single track tubes, which run parallel, 70 m across from each other throughout most of the track, and connecting side tunnels link them every 333 m (Fig. 9).

Between the two main tunnels, and running 12 meters below them, the plan is to construct a preliminary exploratory tunnel. Its main function during the construction phase is to provide detailed information about rock mass. Its position also allows performing important logistic support during the construction of the main tunnel for both the transport of the excavated material as shaft as of construction materials. During the operations, it will be essential for the drainage of the main tunnel.

The excavation process divides into 2 blocks. The first one is planned to bore with n. 3 TBMs (n. 2 for the main tunnels and n. 1 for the exploratory tunnel, direction North), and the second with traditional method, mainly including drill & blast in the competent material and special drilling techniques in the faulty zones, mostly going direction South and in some areas direction North. CIPA S.p.A. Company is currently performing most of the tunnel excavations in the lot named "Mules 2-3" with the French drilling partner Robodrill SA.

7.1 *The design principal*

The system on conveyor belts allows a straightforward, efficient mean of transportation for material going both in and out of concrete crushing, and in and out of mixing plants. It evolves within the carrying out of the project, and gradually implements congruently with the works in progress.

The conveyor system rationalized its complexity since the tender phase (Fig. 10), but always maintaining its high potential, flexibility and capacity. The differentiation of the two belts in Aica (belt 1 and belt 2) allows each single band to be allocated with a certain type of material; therefore belt 1 is for material A (which is good for concrete) and belt 2 is for material B+C (semi-good and not concrete appropriate material). The differentiated configurations avoid alternating different material types thanks to a temporary stocking buffer on the same conveyor. However, the system provides the possibility to switch the material types in Aica according to necessities. This type of realization allows an easier management of the whole system.

We may identify such works into three major phases. This report's aim is to describe the decisions taken within the Construction Project and to list them congruently to time-related phases. Without taking into consideration the specific calculations regarding the Space-Time Diagram of the Executive Work Program, here follows a description of the three phases:

– Phase 1: excavation of the Exploratory Tunnel (CE) by traditional excavating system and TBM assembly chamber; excavation of the first part of the North Line Tunnels (GLN) by

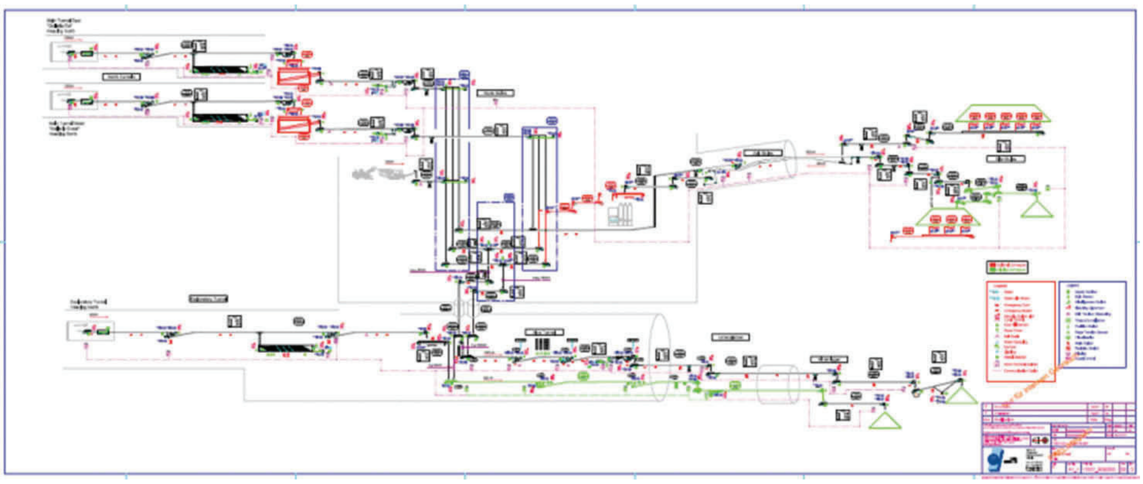

Figure 10. The complex conveyor system general lay out.

Figure 11. Inside and outside tunnel conveyor system.

traditional system and excavation of the South Line Tunnels, always by traditional method (executed by Cipa S.p.A. with 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 (direction North), excavation prosecution of the South Line Tunnels by drill & blast system (GLS); and realization of the mechanized excavation of the CE Northwards.
- Phase 3: prosecution of previous activities, excavation of North Line by mechanized tunneling (GLN) and subsequent finishing job site works.

The complex lay out reported shows the integrated phases.

All belts generally connected to the five excavation faces with the Logistic Knot (N). Subsequently, from Knot N:

- Material type A is carried towards the jobsites Mules and Genauen 2 (deposit area reached by a 180 m length bridge belt conveyor – 300 ton/h – which is crossing the A22 highway, the Isarco river, the National road S.S. 12 and the existing railway line). It is stocked and/or crushed outside and/or gets back to the batching plat, so it can be used for spritz beton, and for the definitive lining in the gallery parts, excavated by traditional methods.
- Material type A/B+C is carried towards the Hinterrigger jobsite and is used to produce the precast elements and the pea gravel, which will fill up the segment over-space during excavation by TBMs. Concrete segments and pea gravel are carried back in through the CE on the dedicated rail system (Fig. 11).

7.2 *Key numbers*

In conclusion, the system has been developed in approx. 80 km (integrated with the existing one, ca. 14 km), with a total installed power of more than 10 MW, which is really a huge number, especially considering the complexity and different working sites (Fig. 12). Below is a synthetic table (Tab. 1):

Table 1. The huge numbers of the conveyor belt system.

Zone	Items	N.	Length, m	Power, kW
Mules logistic knot	Belts	6	211	206
	Chutes	2		
	Dosing units	2		
	Service platforms	3		
Tunnel North	Belt explorative tunnel	1	16,763	
	N-E belt	2	7195	
	Main tunnel N-E	1	13,182	
	Main tunnel N-W	1	13,223	
			50,363	5981
Tunnel South	Belt	1	50	22
Aica - Unterplattner - Hinterrigger	Aica belt	2	10,761	
	Unterplattner - Hiterrigger	1	1169	
	Hinterrigger	2	499	
	Movable stacker	1	48	
			12,477	2778
Adit Mules	Belts	3	1979	673
Site Mules	Belts	6	831	213
TOTAL - new installation			**65,911**	**9.873**

Figure 12. The belt conveyor installation in main the storage area.

7.3 *The system's brain*

The various MCCs (Motor Control Cabinets) are installed in a special container and equipped with a cooling system, which is able to safely handle peak temperatures (of the working environment and produced by the inverters), as far as potential dust.

The belt conveyor system, in its complexity, is fully equipped with a PLC system, which is able to control and command all functions. Touch screen panel designs allow an easy, friendly use.

All critical points have special devices installed, in order to detect potential problems that may happen in its quite long working lifetime, estimated to be ca. 4 years, ahead of time.

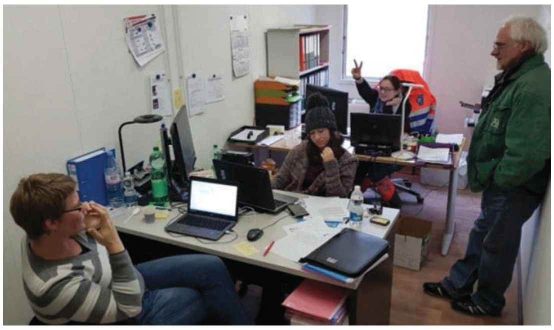

Figure 13. Everything is under control!

Ordinary maintenance planning settles with the various usage coefficients, daily time scheduled availability. In addition, a study of special algorithms allows planning revision caused by the high level of wear and tear, predicted to happen due to the extreme quartz content concentration in the moved rock (mainly granite).

The plan foresees no. 3 control rooms in the critical areas. These will all connect to one another.

The conveyor belt Supplier grants 24/7 Tele-Assistance, thanks to a Wi-Fi connection with the central office based in Switzerland, Moosseedorf-Bern, and an "in situ" job site assistance with electrical – mechanical – electronic & welding supervision, assembling, handling, maintenance and spare parts service (Fig. 13).

8 CONCLUSION

Handling such a variety of complex projects is purely a matter of Teamwork among highly professional Subjects. In no way can one think of this as a simple "purchase and install" procedure. A serious partnership between the Constructor and the Supplier is the key to its success.

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