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Tunnels and Underground Cities: Engineering and Innovation meet Archaeology, Architecture and Art – Peila, Viggiani & Celestino (Eds)

The Fereggiano River Diversion in Genoa

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ABSTRACT: Genoa is frequently hit by disastrous flooding events; therefore, the City has recently implemented part of the works included in the Final Project of the Bisagno river diversion tunnel. Wednesday the 17.02.2016 the Italian Minister of the Ambient stated: "In Genoa we are building one of the most important hydrogeological restructures ever done in Italy". In this document the project related to the first allotment contract, called the Fereggiano River Diversion, is described: a 3.7 km long, 6 m wide tunnel that runs from the intake on the river, in the north of the city, to the east seaside, under some of the most densely populated neighborhood of the city. The excavation under the city with low overburden, the two principal construction sites on the richest seaside of the city and in the narrow riverbed of the Fereggiano, the secondary construction sites in the city tissue are the main issue of the contract.

1 INTRODUCTION

The construction of the Fereggiano River Diversion started in the late eighties, as a service tunnel for the excavation of the more complex project of the Bisagno River Diversion. The work stopped in early nineties because of administrative issues and was left undone for more than twenty years.

After the flood of the Fereggiano River in 2011 that caused the death of 6 people, the Municipality of Genoa, with a noticeable economical effort, financed the first part of the first allotment contract consisting in: the Fereggiano Tunnel (lining inner diameter: 5.2 m; length: 3700 m), the intake on the Fereggiano riverbed with a vortex shaft, the sea outfall and four ventilation shafts. This was the minimal configuration to prevent river flood in the city neighbourhood lying in the Fereggiano Valley. In 2015 the contract between PAC and the Genoa's Municipality was signed.

2 THE MAIN TUNNEL

The Fereggiano Tunnel is a horse shoe shaped 5.2 m wide and 3.723 m long tunnel, with a 0.3% longitudinal slope (Figure 1).

The first 909 m were excavated via an open TBM in the early nineties and left unfinished because of financial problems, after being safeguarded with a cast in situ concrete lining. The section of this first stretch (Figure 1) is narrower than the new Fereggiano Tunnel and with a 2.75 m free span for vehicles is one of the logistic main issue of the work.

The Fereggiano Tunnel (Figure 2) starts with the sea outfall on the "Corso Italia Seaside", one of the most beautiful promenades of the region, then mainly passes under the rich neighbourhood called "Albaro", with an overburden variable between 35 m and 160 m, and ends under the Fereggiano riverbed with a 22 m deep intake shaft.

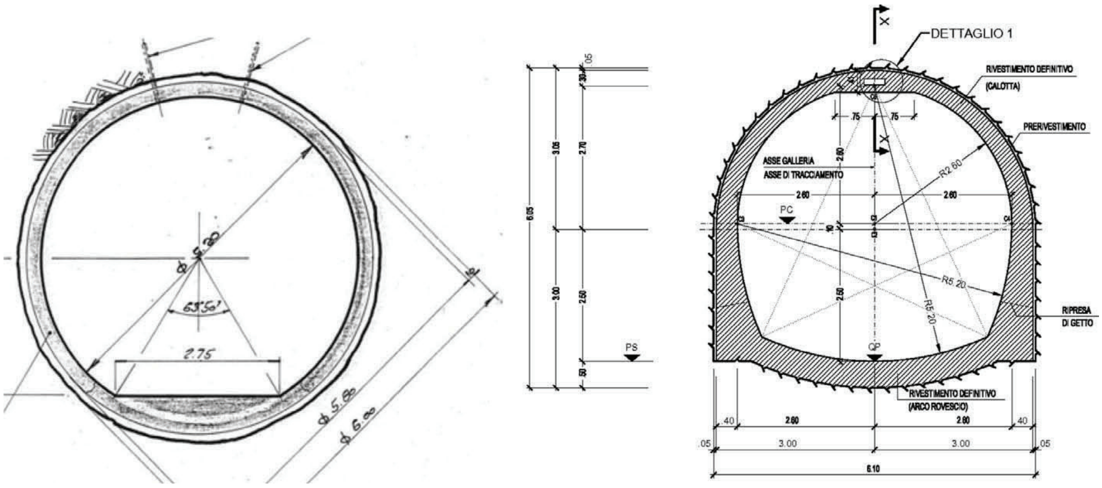

Figure 1. Cross section of: existing tunnel (left) and new Fereggiano Tunnel (right).

Figure 2. Fereggiano Tunnel general plan.

2.1 *Geology*

Almost all the tunnel length pass through the mixed carbonate-siliciclastic flysch of the Monte Antola Formation (Figure 3), having compressive resistance varying from 20 MPa in the pelites layers to 160 MPa in the sound sandstone layers.

This very ancient formation suffered strong tectonic deformation, resulting in a chaotic geometry of the original layers, that sometimes could not be recognised (Figure 4).

Only in a 100 m long stretch the excavation passed through the Ortovero Clays formation, dealing with over consolidated clays and argillites.

2.2 *Advancing methods*

The four typological sections envisaged in The final Design are:

- A0/A0x – with PPFR shotcrete and rock bolts (Swellex type);
- A1 – with lattice girders and PPFR shotcrete;
- B0 – with fore poling, 2 x IPE 160 steel ribs and PPFR shotcrete;
- B1/B1a – with steel pipes, 2 x IPE 160 steel ribs and PPFR shotcrete.

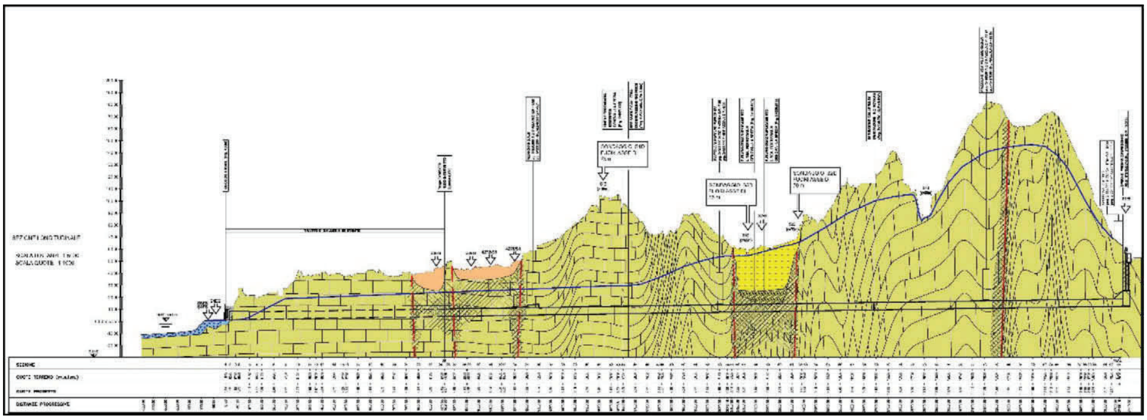

Figure 3. Geological section along Fereggiano Tunnel.

Figure 4. Left: excavation intersect a tectonic fold; because of layers bending, it was hard to keep the correct tunnel shape. Middle: a fully tectonized rock mass, with no sign of the original layering; thanks to re-cementation, the front face was stable. Right: accurate Robodrill robotized drilling protocol in the tunnel.

The B0 section with forepoling was widely applied in poor rock since it allows to advance with the two booms Robodrill jumbo, thus efficiently coping with the fast-changing rock mass condition, instead, the B1 steel pipes section (and consequently the tunnelling rig) was only applied for the most critical stretch.

Given the high resistance of some portion of the rock mass, it was impossible to excavate only by mechanical means (that could minimize annoyance to the urban surface); consequently all the tunnel was excavated choosing day by day between mechanical equipment (either hydraulic breaker or roadheader) and Drill & Blast, depending on rock mass condition.

The use of explosives in a highly populated urban area has been a noticeable issue. Blasting was only allowed in daytime; moreover, the shallow depth of the tunnel required an in-depth study of blasting schemes, day by day updated thanks to the results of the monitoring system. In fact, more than 40 vibrometers were installed along the tunnel alignment, sending data in real in time via gsm to a remote server.

The principles of the blasting design were:

– The use of millisecond delay blasting cap combined with ordinary delayed action cap, in order to minimize the single-phase loading;
– The drill of small diameter holes loaded with small diameter cartridges, in order to minimize linear loading.

The result was a medium incidence of 2.5 m of mining holes each rock mass cubic meter.

All the drilling activities were carried out by the French partner Robodrill, using a two booms fully computerized jumbo, equipped with feeds and clamps for forepoling with self-drilling anchors.

2.3 *The Genoa-La Spezia Railway tunnel Underpass*

Between the chainage km1+560 and km1+596 the tunnel underpass the twin tube railway tunnel "S. Martino", one of the oldest railway tunnel in Italy (half XIX century), with a 3 m vertical diaphragm (Figure 5).

The agreement with RFI (Italian Railway managing authority) established:

- The installation of a monitoring system within the railway tunnels, in order to check in real time strains and displacements in both the rails and the tunnel lining (Figure 6);
- The adoption of a procedure for the risk management, linked to an automatic system of monitoring data analysis and alarm;
- The ban on the use of explosives closer than 20 m to the historical tunnels.

The expected deformations were evaluated by the designer Lombardi Ingegneria via a 3D FEM parametric model and were in real time compared to monitoring results.

After having checked the rock mass quality in the underpass stretch with a 45m long horizontal core drill, a tailor-made typological section called B1a was applied, with the following features:

- n. 33 steel pipes at the crown, L=12 m, step 6 m;
- 2 x IPE 160 steel ribs, step 1 m;
- Double phase PPFR shotcrete.

Given the ban on explosives, the 60 m long stretch was entirely excavated with a roadheader, that experienced poor advancing rates, due to the high resistance of the rock mass; consequently, the excavation of the underpass took about 60 days, with an advancing rate of 1 m/day. Thanks to the very good rock mass quality, monitored deformations were lower than expected and almost nonexistent.

2.4 *Rovare and Noce Rivers diversion chambers*

Along its track the Fereggiano Tunnel will collect waters of two rivers called rio Noce and rio Rovare, by means of two intake-tunnel systems that aren't included in this first allotment. The

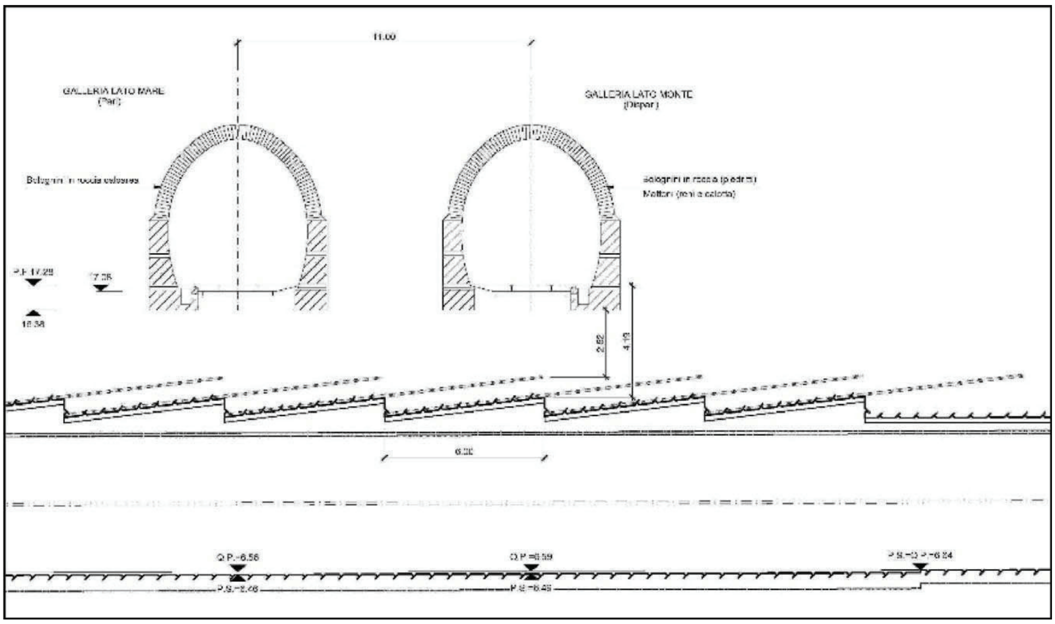

Figure 5. The twin tube railway tunnel "S. Martino" crossing the Fereggiano Tunnel in construction.

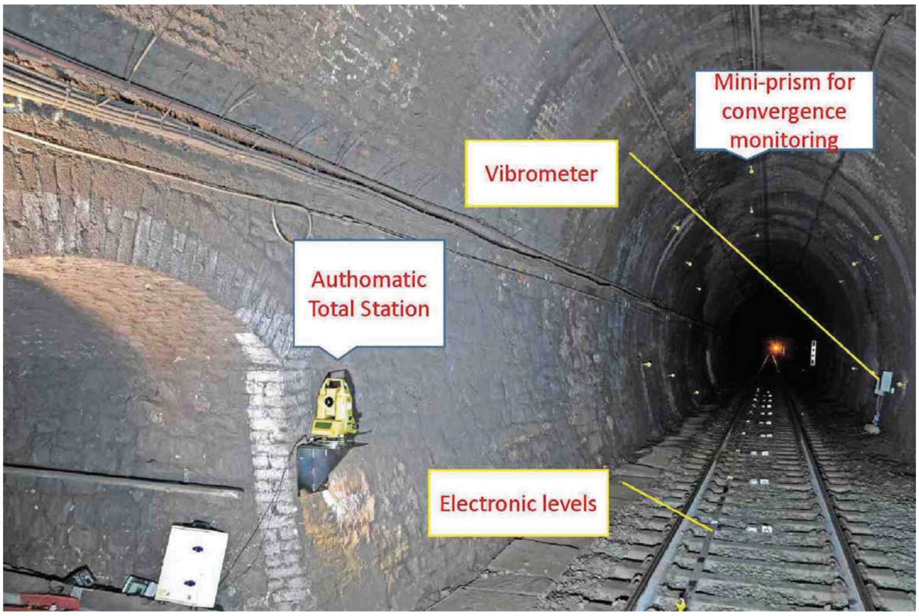

Figure 6. Monitoring system within the historical railway tunnel.

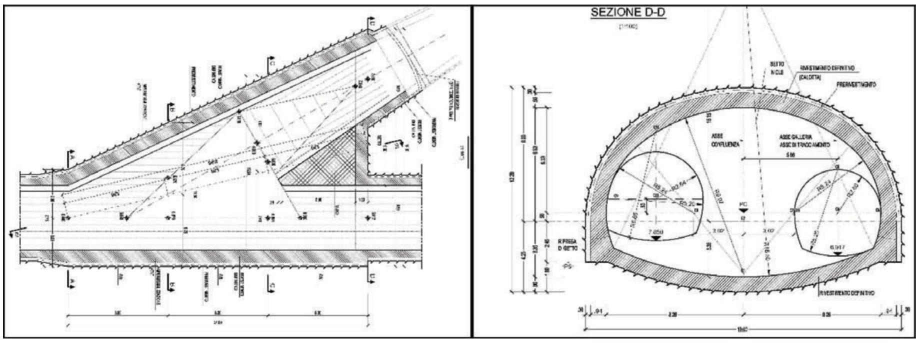

Figure 7. Rovare e Noce Rivers diversion chambers.

only works included in the present project are the two twin diversion chambers, that increase the tunnel span to an internal width of more than 17 m (Figure 7).

The huge sections (as compared to the 6 m span of the line tunnel) were excavated in two phases, with a pilot tunnel on Fereggiano alignment, later widened to the final shape.

The split in two phases of the excavation was compulsory for two reasons: limiting explosive quantity to that allowed in the permit given by the authority and keeping low vibration induced to surface.

The blocky nature of the rock mass, together with the generous span of the excavation (Figure 8), brought to a systematic installation of variable span steel ribs immediately after each advancement phase.

In the widening phase an average advancing rate of 1.5 m/day was experienced, with excavation width varying between 6 m and 19 m.

3 THE INTAKE

The intake system (Figure 9) consists in:

- a concrete structure to be built within the riverbed of Fereggiano River, with a spiral wall that creates a vortex in the water;
- an intake shaft, with 5.9 m internal diameter and 2 2m depth;
- a Venturi chamber excavated at the tunnel level.

Figure 8. Rio Noce diversion chamber and, on the right, the Fereggiano Tunnel.

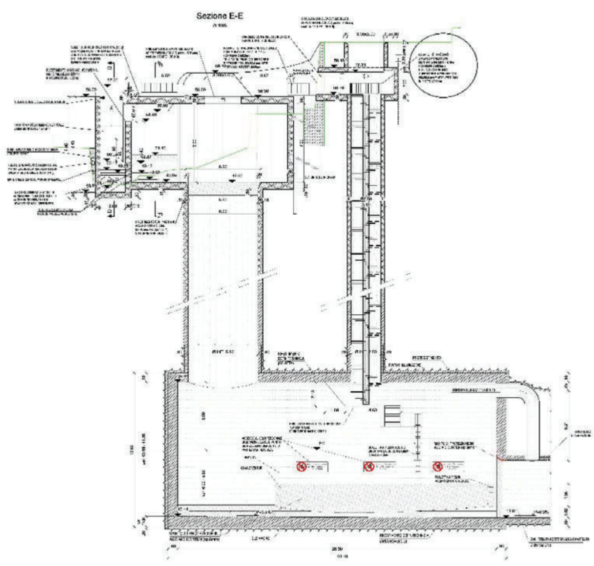

Figure 9. Lay-out of the intake system.

The underground (Venturi) chamber is connected to the surface by means of an access shaft, with 2.5m internal diameter and 35 m depth, that will house a spiral staircase.

The Venturi chamber is a 12 m wide, 26 m long tunnel, excavated via mining methods at the end of the Fereggiano Tunnel, beyond the chainage km 3+723. The excavation will be executed in two phases, with a first phase 8m x 8m pilot tunnel, widened to the final shape after the excavation of the shafts.

The access shaft was excavated via Raise Boring machine (3.03 m nominal head diameter), after having improved a shallow landfill layer 8 m thick with VTR reinforced concrete micropiles and cement moisture injections. Shaft walls have been safeguarded by rock bolts and hexagonal rock net, installed top down by cragsmen.

The concrete final lining of the shaft will be cast down-top with a raising formwork.

The intake shaft has 6.3m excavation diameter; it could not be carried out via Raise Boring because it would require a too large construction site as compared to the available area.

Figure 10. Left - Raise boring pilot hole hits the crown of Fereggiano Tunnel, surveyors breathed a sigh of relief. Right - Beginning of intake shaft widening.

Furthermore, such a large unlined cavity, as it would be if excavated via Raise Boring, could experience stability problems in relation to the blocky nature of the rock mass.

Therefore, a solution combining down-top raise boring and top down enlargement excavation with contemporary lining and support installation has been carried out.

In the first phase, a 2.3 m wide pilot hole has been bored via Raise Boring, in order to have a comfortable way to demuck. In the second phase, the hole has been widened with a hydraulic hammer; each a 2 m step, the excavation was stopped and the shaft wall was safeguarded with wire mesh reinforced shotcrete and rock bolts (Figure 10).

4 THE OUTFALL

The Fereggiano River Diversion will share the sea outfall with the biggest Bisagno River Diversion, that will be soon contracted. Since the Fereggiano Tunnel must operate during the construction of Bisagno Tunnel, the outfall will be completed in this first allotment.

The last hundred meters of the Fereggiano Tunnel lay for a half on the seaside and for the other beyond the coastline; this second section will be hosted in a temporary Landfill, safeguarded by a 3.5m high cliff.

All this stretch will be excavated via cut & cover method, with bulkheads providing support and waterproofing. The choice of bulkheads technology was influenced by two conditions:

– the proximity to the sea, involving the risk of water pollution;
– the presence of a shallow bedrock, unfavorable for diaphragm walls or large diameter pile walls.

Finally, a mix of two technologies was adopted:

Figure 11. Left: 1280mm secant piles on the landfill. Right: excavation under the sea level.

- on the seaside, the wall is composed by bi-fluid jet grouting columns Ø1000mm and micro-piles Ø350m i.d. reinforced by HEB200 steel beams;
- in the off-shore landfill, a pile wall with 1280mm diameter secant piles is envisaged.

5 VENTILATION SHAFTS

Along the track of the tunnel four ventilation shafts 600mm i.d. had to be built, varying between 35m and 90m in depth.

Depending on ground conditions, two technologies were applied:

- In stable rock, shafts were bored via R.B.M. machine,
- In soft soil or mixed ground conditions, shafts were bored by a light drilling Rig.

At the end, two shaft was excavated by R.B.M. and the other two via Drilling Rig.

One shaft, intersecting the tunnel near to the middle, was over-bored to an internal diameter of 1000mm and used to provide fresh air to the tunnel advance. The main issue of the ventilation shaft sites, all located within densely populated neighborhood, were the lack of space and the difficulties to access by truck and other heavy vehicles.

The R.B.M. technology proved to be the most versatile, being possible to divide the site in a very small area at the head of the shaft (Figure 12) and in a second area, linked via pipes and electric cables (housing electric generator, air compressor and other facilities), that could be hundreds of meters far away. Founding the area for the Drilling Rig was more difficult:

- in one case the closure of a carriageway of via Ricci, a street in the city center, was needed;
- the other site was located within a flowerbed in S. Martino Hospital area, taking up not more than 200square meters.

6 LOGISTIC

The most critical issue of the contract was undoubtedly the location of the main site on the seaside, within a unique landscape and in the center of a prestigious neighborhood.

In the tender phase competitors were asked to find the way to mitigate the impact of the site on this sensible context.

PAC submitted to the Commission the idea of constructing a large hangar, lined with phono-absorbent panels and painted in order to minimize sight impact on the environment, that would house all the facilities needed by the site; the idea was very well considered and brought PAC to win the tender.

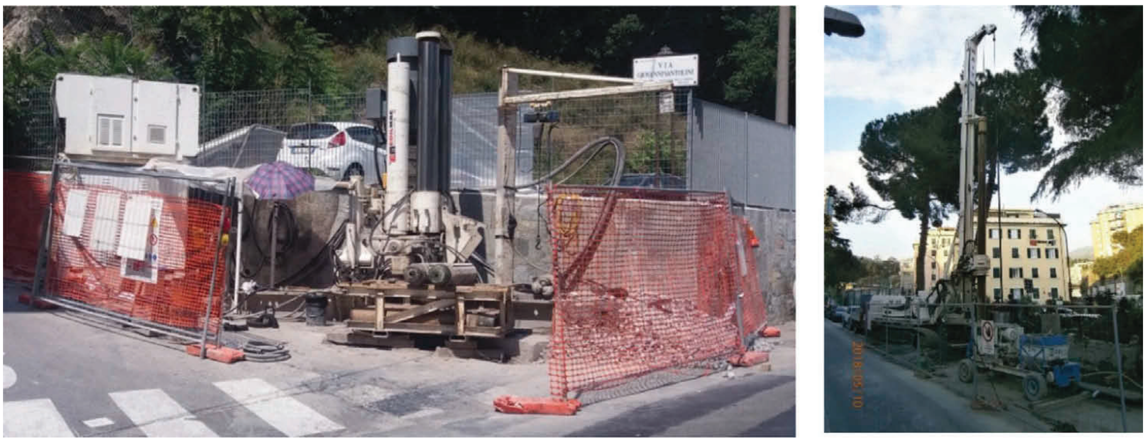

Figure 12. Left: R.B.M drilling site. Right: Drilling Rig within S. Martino Hospital area. All very narrow areas.

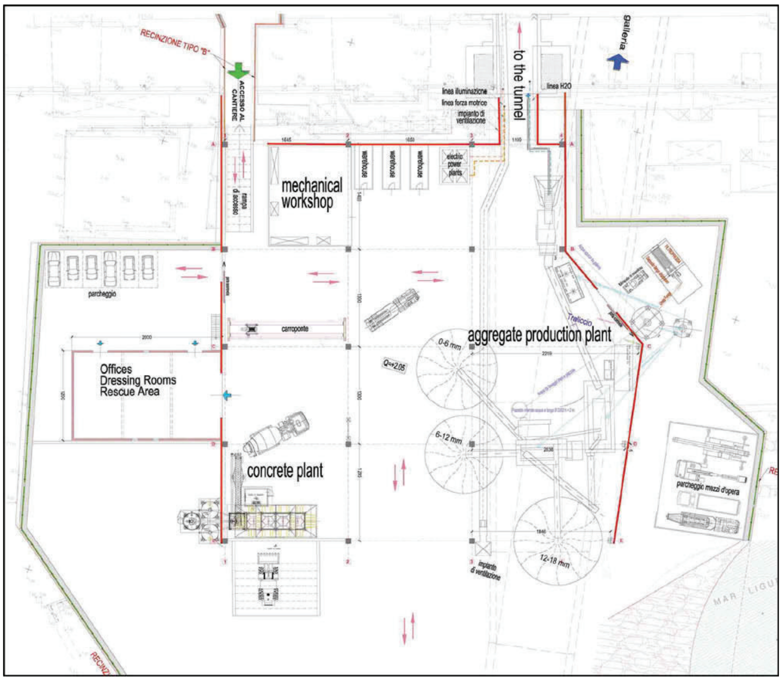

Figure 13. Main Site lay-out.

Figure 14. The Hangar from the promenade (left) and inside – quite different!.

Figure 15. Barge loading in front of the hangar.

The hangar houses site offices and plant for aggregate production, concrete plant with aggregate storage area, mechanical workshop, Electric power plants, fresh air supply plant and water treatment plant.

As prescribed by the contract, al the muck was carted away by the sea, brought to Genoa harbor and then carried by track to final destinations. The loading of the muck (Figure 15) was carried out by a crane equipped with a clamshell, working from a barge.

7 CONCLUSION

The primary task of this job was probably not only to excavate the tunnel, a complicate long one with quite a restricted section and different other engineering tasks, but mainly to cope with the delicate urban environment.

Company PAC S.p.A. designed a complete on shore plant installation, comprise of ventilation, dedusting, dewatering, crushing, belt conveying, ship muck loading plants, everything protected and hidden to the human habitants in a very delicate habit.

Only well-organized Planning, sensitive Technicians and Miners, good selected Partners and an intelligent Client could lead to the success such a job. Lesson to be learnt and followed!