Les galeries de la nouvelle autoroute Pedemontana Lombarda

The tunnels of the new Pedemontana Lombarda motorway

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Résumé

La nouvelle autoroute Pedemontana Lombarda est une partie du territoire à des moments urbanisée, avec la présence de contraintes importantes à la frontière, comme les bâtiments, les routes et les voies ferrées, voies navigables, etc.. Afin de limiter autant que possible l'impact généré par le nouveau travail sur le contexte actuel, le trajet se développe pour la grande partie en souterrain, avec différent types de tunnels. Les temps serrés disponibles pour l'ouverture à la circulation de la première étape de connexion avec les autoroutes A8 et A9 existantes, on a poussé autant que possible d'industrialiser le processus de construction. A cet effet, pour le projet et la réalisation de galeries naturelles on a employé le système ADECO-RS tandis que pour la construction de galeries artificielles avec arc on a mis en place un système innovant de préfabrication. Dans la mémoire on présentera en détail les solutions de conception adoptées, en montrant les avantages importants par rapport aux temps d'exécution brefs, en vue d'une qualité remarquable des travaux. Au sujet des tunnels classiques, pour contrôler la réponse de la déformation du sol causés par l'excavation, des traitements de "jet-grouting" ont été utilisés, améliorant ainsi les propriétés de résistance et contribuant activement à la stabilité de la face du front de taille et de la cavité. Pour les tunnels cut&cover le système se compose d'une structure de type arc, composé de trois éléments préfabriqués: une voûte dans la partie supérieure et deux parois latérales, installées sur le radier du tunnel en béton armée coulé sur place. L'effet fourni par la géométrie courbe des éléments de construction et par le confinement latéral offert par le remblayage, augmente les capacités statiques de la structure, lui permettant de supporter des charges lourdes (c'est à dire des hauteurs significatives de recouvrement).

Abstract

The new Pedelombarda motorway fits in a territory at times urbanized, with the presence of significant constraints such as buildings, roads, railways and waterways. In order to limit as much as possible the impact generated by the new work on existing context, the track has made extensive use of underground space, built both conventional tunnels as cut&cover tunnels. The tight time available for the opening to traffic of the first leg, connecting the existing A8 and A9 motorways, pushed to industrialize the construction process as much as possible, using the ADECO-RS approach for the design and construction of tunnels and introducing an innovative prefabrication system for the construction of cut&cover tunnels. In this paper we present in detail the design solutions, showing the important advantages with respect to the containment of the execution time, compared with a remarkable quality of the works. In conventional tunnels, to control the deformation response of the ground caused by the excavation, "jet-grouting" treatment were employed, thus improving ground strength properties and actively contributing to the core-face and cavity stability. For cut&cover tunnels, an arch-type structure made up of three pre-fabricated elements was considered: a top vault and two sidewalls, installed on an invert cast-in-place. The shape effect given by the curved geometry of the construction elements and by the confinement offered by the lateral backfilling increases the static capacities of the structure, allowing it to support heavy loads (i.e. significant overburdens).

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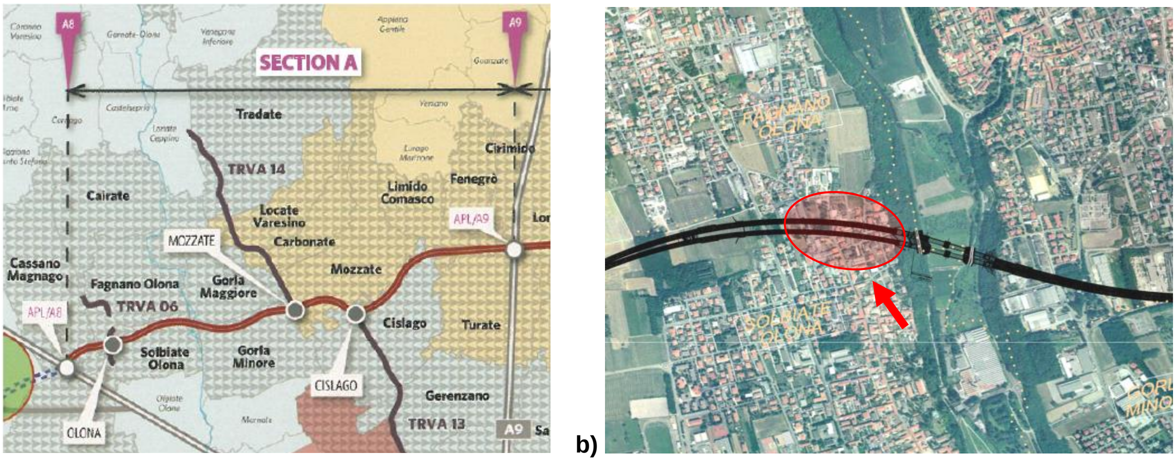
1 Introduction

The new Pedemontana Lombarda Motorway – 87 km long and adding almost 70 km of new viability – is a key system for the mobility of its territory. It will be able to move 350,000 vehicles each day through an area inhabited by almost 4 million people. The first step towards this important network is "Section A", the works of which were contracted to the General Contractor "Pedelombarda" S.c.p.A, built by Salini-Impregilo S.p.A, Astaldi S.p.A., Impresa Pizzarotti & C. S.p.A. and A.C.I. S.c.p.A. These works began in February 2010 and were completed last December. This first section (14.5 km long) links the existing A8 "Milan-Varese" motorway and the A9 "Milan-Chiasso" motorway (Figure 1a), within a partially urbanized territory, including existing infrastructures such as roadways and tracks, as well as constructions and watercourses. The motorway alternates trench sections with tunnels, limiting the impact on the territory as much as possible. After under-passing the Provincial Road 20 and 2 with cut&cover tunnels, the route interferes with part of the inhabited area of Solbiate, which is therefore under-passed in conventional tunnelling (Figure 1b). The motorway crosses the river Olona, by means of a viaduct, and continues on towards Gorla Maggiore, again in cut&cover tunnel so as to preserve the existing local viabilities; the last cut&cover tunnel is located in Cislago.

a)



b)

Figure 1. a) Motorway "Section A" b) "Solbiate Olona" Tunnel

Rocksoil S.p.A. provided the final and detailed design of the "Solbiate Olona" conventional tunnel and the final design of the cut&cover tunnel using pre-fabricated system. Scope of the design was to reach a high level of industrialization of the construction process, to maintain the estimated times and costs. For the conventional tunnels, jet-grouting technology was adopted according to A.DE.CO-RS Approach in order to guarantee idoneous safety conditions, to the pre-existing structures too. For the cut&cover tunnels, an innovative typology of arch shaped pre-fabricated linings was adopted to cope with major heights of backfill cover, thanks both to the structural shape-effect and ground arch-effect mobilization; Codelfa S.p.A. and Impresa Pizzarotti e C. S.p.A. constructed the prefabricated tunnels and Simete S.r.l worked on the detail design. This paper, after an overview of the works and the geological context, aims to illustrate in detail the construction system used and the monitoring data collected.

2 Brief overview of the works

The Solbiate Olona tunnel is made up of two bores (one for each direction), respectively 1,175 m and 1,178 m long; 464 m and 457 m of which in conventional tunnel, with a 35 m distance between the axes. The carriageway is made up of three lanes for each direction; two of them are for traffic (each

3.75 m wide), and the third for emergency (3.00 m wide, with a side platform on the left 0.70 m wide). In order to guarantee visibility on bends for the design speed of 80-140 km/h (in presence of a planimetric radius of curvature equal to 1,350 m and of transversal inclinations equal to up to 5.8%), the east-direction carriageway presents a widening equal to 0.50 m on the right side, while the west direction carriageway presents a widening equal to 2.60 m on the left side. This brings about significant cross sections, with an excavation area of 190 m² for the East bore and 230 m² for the West bore (Figure 2a). The tunnels are connected with vehicular bypass, every 300 m, pedestrian bypass, every 900 m, and emergency refuges every 600 m. The tunnel presents very modest crown overburden, averagely between 10 and 13 m, inferior to the excavation diameters of 17 m for the east bore and 19 m for the west bore (H/D ratios within the range of 0.5-0.7). This situation is complicated by the presence of buildings on the ground level for a large portion of the alignment (see Figure 2b). For the most part these are 2-3 stories buildings built in the 1960s and 1970s, with a mix of load-bearing walls and hollow-core slabs; a few of these are also one-story industrial structures. In some cases the basement level is 2-3 m below the ground level. The presence of buildings, and the need to keep them inhabited during the works, need to limit the “ground volume loss” during the excavation, so as to control the subsidence at the ground level and any effects on the pre-existing structures.

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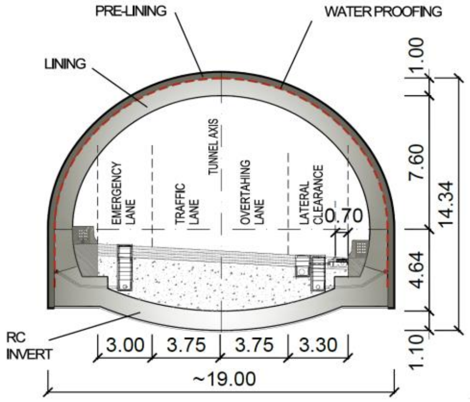
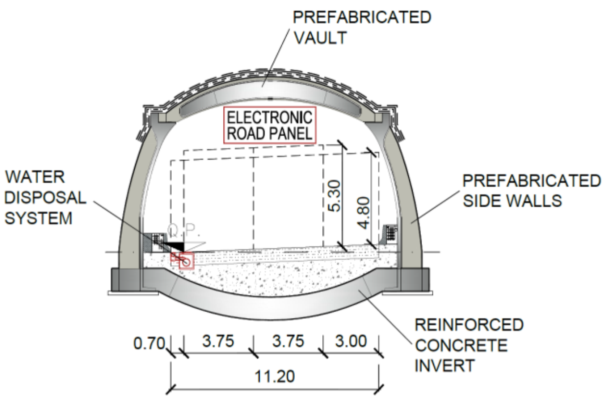


b)


Figure 2. a) Conventional tunnel section layout b) Tunnel plan vs pre-existing structures

The main cut&cover tunnels along the motorway were constructed with pre-fabricated elements: the “Solbiate Olona” (670 m long), “Gorla” (1,280 m), and “Cisalgo” (474 m) tunnels, named according to localities. In order to guarantee visibility for planimetric radii of curvature varying from 1,260 m to 1,350 m, the road presents carriageway in the range 13.5-19.0 m, with overburden on the crown in the range 1.0-9.0 m. The internal profile of the tunnels guarantees heights equal to 5.50 m from the road, due to the presence of signage on the crown (min. net gabarit: 5.0 m). Each tunnel includes emergency exits every 500 m, using lateral shafts equipped with emergency staircases. Emergency refuges are also positioned every 600 m, and constructed by widening the road 3.0 m on the right. Considering the different types of carriageway used, the tunnels were constructed of variable diameter between 15 m and 20 m, with invert intrados/crown extrados between 12.75 m and 13.45 m. Tunnels geometry also had to take into account the constraints brought upon the invert by the water-disposal system, as detailed in Figure 3a.

a)


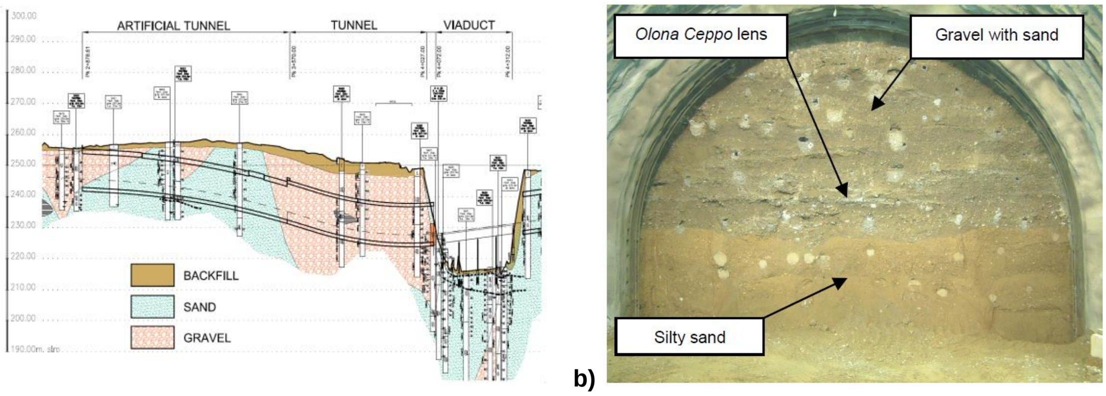
b)


Figure 3. a) Arch-shaped tunnel section b) Solbiate Olona Tunnel – C&C tunnel close to tunnels portal

3 Geological and geotechnical context

The tunnels are located within the pleistocenic glacial sediments in the amphitheatres of Verbano and Lario, and the corresponding fluvial and glacial sediments. The fluvial sediments, besides the recent ones, which occupy the current waterbeds, are limited to conglomerates called "Ceppo", which deposited during the long interglacial period between the late and middle Pleistocene; these were made up by clastic support conglomerates with variable levels of cementation – ranging from good to bad.. The "*Besnate Allogroup*" and the "*Binago Allogroup*" were found along the tunnels' path. The Solbiate Olona tunnels were almost exclusively constructed in deposits of gravels and silty sands, belonging to the lithological–geotechnical unit of "prevalent gravels"; Figure 4a reports the geological profile and Figure 4b reports a typical geological face mapping.

a)



b)

Figure 4. a) Tunnel geological profile (H=2-13 m) b) Geological face mapping

The Gorla tunnels passed through deposits of sand with silty gravels belonging to the lithic-technical unit of "prevalent sands"; furthermore, "Ceppo" lenses and outcrops were faced during excavation. Finally, the Cislago tunnels developed in sandy grounds with silty gravels, belonging to the lithological–geotechnical unit of "prevalent sands"; silty-clayey levels occurred also during the excavation phase. The Solbiate Olona and the Gorla tunnels didn't encounter any criticalities from the hydrogeological point of view, as they didn't interfere with the watertable, whose depth is greater than 35 m. The excavation of the Cislago tunnels encountered local perched watertable, probably formed by accumulation over the impervious silty-clayey layers. In any case, the amount of water was modest. Table 1 reports the parameters of strenght and of deformability of the excavated grounds, in function of their depth. For the cut&cover tunnels' numerical evaluations, it was also important to define the value of the vertical Winkler constant k_w, estimated in the range 2-4 kg/cm^3. Finally, for the seismic site conditions, the peak bedrock horizontal accelerations a_g are equal to 0.054g as regards the Life-Safety Ultimate Limit State, and 0.031g as regards the Serviceability Limit State, taking into account a nominal life V_N of 100 years with a class of use coefficient cu = 2.0 (period of reference V_R = 200 years).

Table 1. Geotechnical properties of natural soils (average values)

Stratigraphy	Depth m	γ kN/m^3	c' kPa	ϕ' kPa	E MPa
Backfill	0-1	18,0-19,0	0	28-30	10-20
Sand with silty gravel	<15	19,0-20,0	0-5	32-36	20-50
Sand with silty gravel	> 15	19,0-20,0	0-5	32-36	50-100
Gravel and silty sand	lents	19,0-20,0	0	34-38	20-50

4 Conventional tunnels construction system

In order to control the deformation response of the ground caused by the excavation, it was necessary to consolidate the granular material affected by the tunnel, thus improving their strength properties and actively contributing to the stability of the face and of the cavity. The granulometric and permeability properties of the materials made it clear that "jet-grouting" was the best technology for treating significant volumes in short periods of work, especially when compared with other injection and strengthening systems.

4.1 Jet-grouting technology

Jet-grouting consists of injecting fluid mixtures at an extremely high velocity through one or more nozzles placed at the end of a hollow rod; the fluid jets mechanically break up and permeate the ground, thus cementing it around the injection point. This brings about the formation of columns, the diameters of which depend on the executive operational parameters of “jet-grouting” and on the parameters used (Lunardi et al., 1986). When using one grout mixture only, made of water and cement (“mono-fluid” procedure) the columns formed in the examined granular material are 600-1,000 mm in diameter; higher diameters (up to 1,500-1,800 mm) can be achieved by adding compressed air to the cement grout (“bi-fluid” procedure). Due to their potential application both in the tunnel and on the ground level, both procedures were investigated through specific field tests in order to evaluate the idoneity of the technology itself, and to set the optimal operative parameters. The field tests were carried out during the open-air excavations for the construction of the portal, and they required column treatments with different sets of operative parameters. The columns were then controlled visually for the first 5-6 m from the ground level (Figure 5a), until the continuity of the treatment in depth was verified with bore probing. Finally, samples of the treated ground were taken and subjected to mono-axial compressive stress tests in order to define the resistance properties. The results of the field tests were highly satisfying, both in terms of diameter (the bi-fluid procedure brought about diameters within the range of 1,450-1,700 mm), and in terms of continuity of the treatment in depth, where the probes registered RQD>70-80%. The stress tests showed an average compressive resistance equal to 8.7 MPa, higher than the design prescribed level (5 MPa).

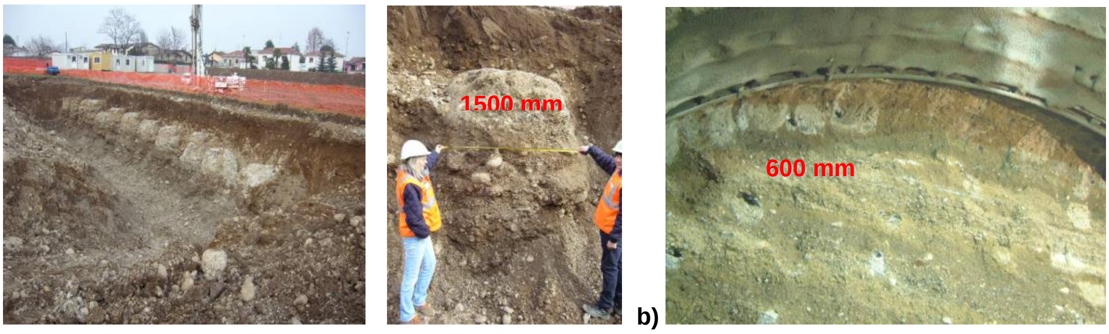
a)


Figure 5. a) Jet-grouting field tests (bi-fluid 1500 mm) b) Jet-grouting treatments (mono-fluid 600 mm)

Table 3 reports the identified operative parameters used during the works; the injection grout had an A/C ratio equal to 1.0. The “bi-fluid” grout used an air pressure of 8 bars with range 8 m^3/min. Cement was consumed at a rate of 210-230 kg/ml for treatments 600 mm in diameter, and 800-850 kg/ml for treatments 1,500 mm in diameter. Of great importance is the control over the energy balance with respect to the operative parameters, according to Tornaghi (1993): treatments 600 mm in diameter required specific energies of 11-14 MJ/ml, while treatments 1,500 mm in diameter required specific energies of 42-46 MJ/ml. The company SGF–INC S.p.A., carried out all jet-grouting treatments.

Table 2. Jet-grouting operative parameters

Procedure	D (m)	Pr (b)ar	Nozzle (N, mm)	Vex (cm/min)	Vr (g/min)
Monofluid	600	360-400	3, 2.6	60-80	15
Bifluid	1500	400-420	2, 4.0	30-32	9.38

4.2 Construction method and phases

The stabilizing actions of the core-face and of the cavity, and the succession of construction phases to adopt, were chosen with reference to Lunardi (2008). Strengthening measures were carried out while advancing to form an artificial “arch effect”, with a protective function for the core-face and to limit the detensioning of the ground following the excavation. The strengthening of the face guarantees the stability of the core, avoids the release of ground and minimizes extrusion deformation phenomena. Thanks to the adopted actions, the excavation can take place within stable material, which reflects into a great reduction of ground pressure on the lining, of the tunnels deformation behaviour and of the surface subsidence. It's therefore possible to operate the "full face" excavation, also with geometries equal to 230 m², thus favouring the fast stabilization of the cavity thanks to the invert casting.

The availability of space allowed operations to take place from the ground level for the first section starting from the Cassagno Magnano side portal; this allowed the formation of column treatments, which were 1,500 mm in diameter. This also formed a belt of strengthened ground along the perimeter of the cavity equal to 4 m for the crown and 3.5 on the sidewalls, as can be seen in Figure 6a (section type C1c). The geometry of the treatment was studied in order to obtain a squared mesh, downhole, of 1.10 m x 1.30 m, and therefore guarantee the compenetration of the treatments. Drillings were carried out for a length of 19-20 m, with an un-injected section of about 8 m. The excavation face was treated using consolidated diaphragm 4 m thick for every 15m, capable of partitioning the tunnel excavation. The pre-lining was put down by using ribs 2IPN180/200 (east/west bore) at the pitch of 1.0 m and embedded within a layer of 30 cm thick fibre-reinforced shotcrete, with 5 cm of regularization. The casting distance of the invert is about 40-50 m from the face.

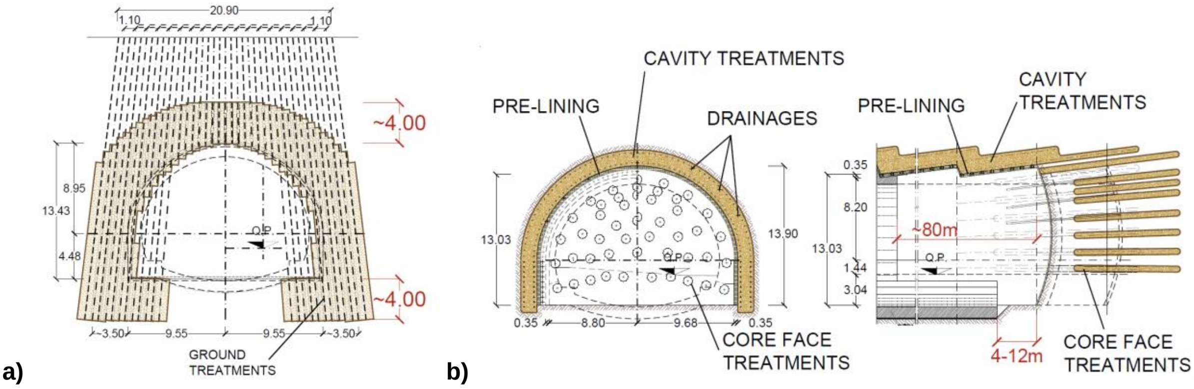


Figure 6. a) Section type C1c b) Section type C1a

The treatments were carried out in advancement for the rest of the tunnel, following a sub-horizontal truncated-cone shape and nominal diameters of 600 mm. The treatments geometries were studied according to the presence or lack of pre-existing structures on the surface. The section presenting buildings on the surface required double rings of treatment at the outline of the cavity, thus laying a thicker consolidated strip (equal to 1.10-1.30 m) and, especially, guaranteeing the continuity of the treatment in the presence of local treatment defects. In this case (section-type C1a, Figure 6b) treatment lengths equal to 18 m were adopted, with advance fields equal to 8 m; the repetition of the treatment causes a double overlap along the perimeter of the tunnel with an extra margin of 2 m. The treatments were set at an interaxis of 0.50 cm, with 69 columns in the east bore and 75 columns in the west bore. Consolidation of the core face required the creation of 30 columns in the east bore and 41 columns in the west bore, these are 18 m long and overlapping 10 m (with 4 m of uninjected drilling). The pre-lining is the same of the section-type C1c. The casting of the invert was kept near to the excavation face (varying between 4 m and 12 m – beginning and end excavation of the advance field) in order to minimize the deformation response of the pre-lining. The maximum distance from the crown casting face is equal to 80 m. Where buildings were absent on the surface, the strengthening lengths along the perimeter were equal to 14 m, with advance fields of 9.0 m, and overlapping of 5.0 m (uninjected drilling equal to 1.5 m); in this case 69 columns in the east bore and 75 columns in the west bore were used. The strengthening of the core face used 30 columns in the east bore and 41 columns in the west bore – 16 m long, an overlapping of 7 m (section-type C1b). The pre-linings used were the same as those of the section-type C1a, with the distance of the casting of the invert from the face equal to 15-20 m. The planimetric diagram shown in Figure 2b indicates the sections in which the section types were used. All final linings are in reinforced concrete class C25/30 (XC2).

On site, the work cycle was organized into three main phases: 1) treatment, at the face and at the perimeter, 2) advance excavation, for single excavation steps of 1.0 m, followed by the setting of the pre-lining, and 3) the casting of the invert, as shown in Figure 7. Other actions - such as the waterproofing, the crown reinforcement and the casting of the final lining – are carried out of the critical path, solely conditioning the advancement of the nearby bore, which, due to the reduced septum between the two bores, must flank an already-lined tunnel.

Figure 7. Main execution phases: grouting treatment, excavation and invert casting

The average duration of a work cycle was about 7-8 days: 45% of the time was dedicated to the treatments; 40% to the excavation phase, and the setting of the pre-lining, 10% for the invert; a minor percentage was dedicated to collateral activities. The excavation started in October 2011 at the portal on the Cassano Magnano side, and proceeded without interruption and with high regularity. The construction process resulted heavily industrialized, as can be seen in Figure 8, which exemplifies the production of the east bore in m/month and m/day. Notice the regular monthly production, equal to 30-34 m/month (excluding the months of August and December, with suspensions due to the summer and Christmas holidays), and average daily production of 1.00-1.20 m/day. The advancement (the blue line) is practically linear; this stands as testimony to how a careful initial design can help industrialize excavation, and therefore optimize construction times and costs. The drilling of the east bore took place in February 2013, the west bore was completed in April 2013.

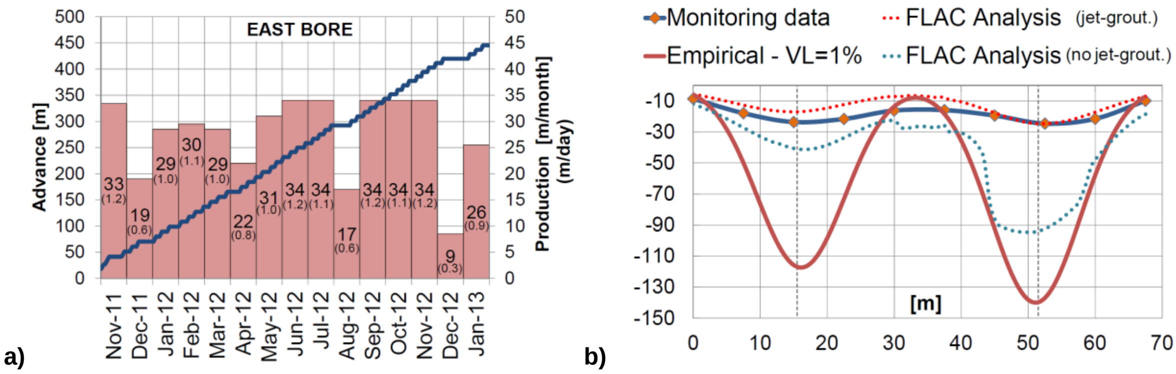


Figure 8. a) East bore production b) Ground level subsidence (mm)

Control of the deformation response was carried out by means of a monitoring plan requiring systematic cavity convergence measurement stations within the tunnel; these used optic targets placed on the pre-lining (1/advance field). A topographic levelling network was also installed at the ground level. The collected data confirmed the deformation response that had been foreseen by the numeric analyses during the project phase: the core face proved to be "stable" after the treatment, with a few negligible deformations; The cavity movement measures also gave very small convergence values, in the 3-8 mm range, below the defined range limit of 25-50 mm. The most significant monitoring regarded the measure of the subsidence at the ground level: the topographic measuring systems indicated subsidence in the range of 15-25 mm (as reported in Figure 8b), lower than the attention and alarm levels (35 mm and 50 mm, respectively). The amount of "lost value" was equal to 0.3% of the excavated volume – this was much less than that generally reported by the literature for traditional excavation (where the "lost volume" is generally around 1.0-2.0%). According to Figure 8b, the subsidence basin under consideration is reported using the usual empirical formulations (O'Really and New, 1982) with a volume of "lost volume" equal to 1%, despite how the numerical evaluations use analyses of finished differences – with FLAC calculation code – in the absence of actions and using the projected jet-grouting treatments. Notice how this last simulation fits in very well with the monitoring data, proof of how the advancement modalities used were successful in keeping the disturbance on the ground extremely low, in line with the mechanical system excavation solution.

5 Cut&cover tunnels construction system

The innovative system used for construction consists of an arch-type structure made up of three prefabricated elements: a top vault and two sidewalls, installed on an invert cast-in-place. The shape effect given by the curved geometry of the construction elements increases the static capacities of the structure, allowing it to support heavy loads (i.e. significant overburdens), while continuing to adopt the usual prefabricated cross sections in reinforced concrete. Two solutions were employed, according to the layout of the two carriageways. Wherever the inner distance between the two carriageways maintained a significant diaphragm between them (at least 3 m), a "twin tunnels" solution was used; creating two separate tunnels (Figure 9a). On the other hand, when the distance was limited, an "adjacent tunnels" system with a shared central pillar was implemented (as shown in Figure 9b).

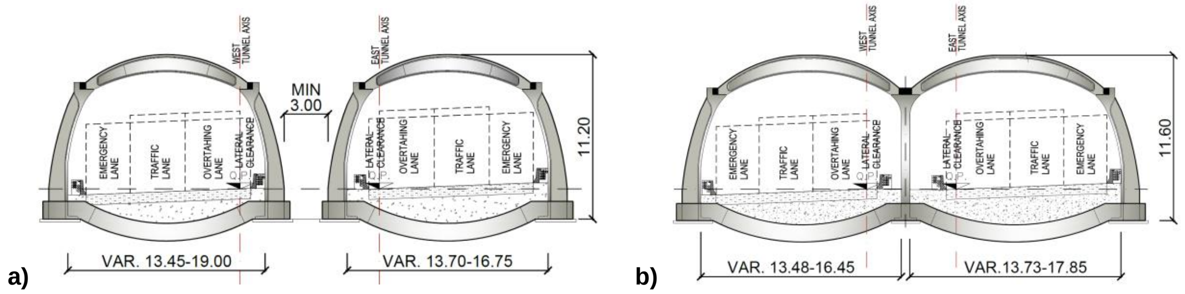


Figure 9. a) Separate b) Adjacent twin tunnels – typical layout

For the top vault precast-element a double T-section curved frame was used having a higher and lower wing 124 cm wide, and variable in thickness – from 8 to 15 cm (higher wing), and from 5 to 8 cm (lower wing). The height, at crown top, where the bending moment is maximized, was determined in function of the overburdens according to following three types: 100, 120 and 150 cm, with a 15 cm web. The height of the element also varies along the main axis, being reduced towards the supports, where the section presents heights between 94.70 (minimum) and 112.10 cm (maximum) according to the three structure types and the span-widhts involved. A full rectangular section is applied for the last 2.0 m close to sidewalls connection, in order to hold the maximum shear stress (Fig. 9a). The axis of the element is curved, with a radius between 8.68 and 10.56 m. A "pi-greek" section geometry was chosen for sidewalls elements, 249 cm in length and 130 cm in height; the element contains two webs – from 23 to 27 cm thick – attached to a wing in the intrados of the tunnel, 16 cm thick. The sidewall is also curved, with a radius equal to 3.47 m (Fig. 9b). Both prefabricated elements are in concrete, class C45/55, with ordinary steel reinforcement. Main steel reinforcements, Ø22-26 mm bars, were adopted at the base of the web, coupled with secondary-reinforcement Ø16 bars, both in B450C steel.

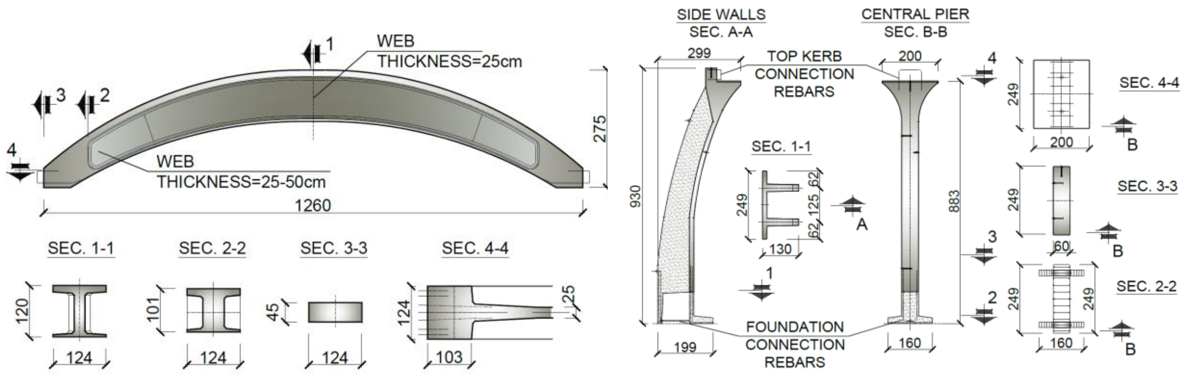


Figure 9. a) Prefabricated vault-element (H 120 cm) b)Sidewalls/central pier prefabricated elements

The structural coupling requires each sidewall-element to support two prefabricated vault elements, so that the wings of the sidewalls and of the vault elements make up the uninterrupted intrados of the artificial tunnel. Finally, the structural outline requires an invert, cast-in place with class C25/30 reinforced concrete, 120 cm in width and with a radius of curvature varying between 13.55 and 15.79 m. The design stage of the technical details for the connections between invert and sidewalls-base and vault-elements and sidewalls-top was of great importance; special solutions were developed to speed-up the placement of the prefabricated elements during the works, guaranteeing reliable static efficiency as well. It was decided to guarantee the structural continuity between sidewalls base and the invert (joint constraint, Fig. 10a), thus providing an overall structural stiffness. A pin constraint was chosen for the vault-sidewall node, capable of absorbing any rotation of the covering element at the support. The sidewalls and vault elements at the extremity are also equipped with reinforced stirrups, external to the cast; in this way, once placed together, they can be joined with steel reinforcements lengthwise and connected with an integrative cast while work progresses. Thanks to this longitudinally continuous solution at the height of the sidewalls, alongside the structural continuity at the invert, the structure exhibits sufficient horizontal stiffness when facing seismic activity. The description of the construction details and of the waterproofing system are described in Lunardi and Gatti (2014).

Figure 10. a) C&C Tunnel and temporary retaining structures

The first construction phase consists of open-air excavation to meet the base levels of foundation inverts (slopes 1/1, protected with shotcrete and with intermediate berms every 6 m in height); near existing structures temporary retaining structures were set up (Fig. 10c). In the second phase the middle portion of the invert is cast, to create a work track for prefabricated elements supply. Than the sidewalls-prefabricated elements are positioned (Fig. 10b) and connected to the invert. The vault prefabricated elements are placed, and the vault-sidewall node is defined to create longitudinal continuity (kerb). The third phase provides the waterproofing setting and the lateral and top backfilling. Positioning tolerance was equal to 10-15 mm, requiring modest joint corrections with specific sealing. As regards the construction times, these average daily production were recorded: 12 m cast-in-place invert, 8 sidewall prefabricated elements, 16 vaults prefabricated elements and 50 m top kerb.The methods used for the backfilling, as well as the materials employed, are of the utmost importance due to the “arch” geometries chosen for the C&C tunnels, as they determine the static performance of the work. While the backfilling material above the vault determines exclusively a lithostatic load operating on the structure (γ=20KN/m^3), the lateral backfilling material should be considered an integral part of the resistant “structural system”, as it exerts the horizontal confinement necessary for the static effectiveness of the structure. For this reason, the static calculations were carried out taking into consideration not only the strength properties of the backfilling materials (ϕ’=35°, c’=0), but also the deformability parameters, in order to evaluate the level of confinement offered by the backfilling to the structure (E=70-100 MPa, K_h=1.0 kg/cm^3). The geotechnical parameters of the backfilling soils depend heavily on the method used for construction, especially on the given level of compaction. For this reason, during the construction, “Repetitive Static Plate Load Test-PLT” were done together with in-situ density measures by means of sand volumometer. These tests were performed on loading-unloading cycles, and allowed the calculation of Young’s elastic modulus and consequently the horizontal reaction modulus k_h through well-known Boussinesq’s equation, $k_h = E / (B\ (1-\upsilon^2)\ I_w$, (see Lunardi and Gatti, 2014). Thus, these trial-tests both helped to evaluate the properties of the materials used, and the idoneity of backfilling-material layering and compaction methods.

6 References

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