The Livio Cosenza Tunnel: the first step towards the urban transformation of the Flegrean Area (Pozzuoli, Na)

Georgios KALAMARAS
AK Ingegneria Geotecnica Srl – Turin
Carlo ALESSIO
AK Ingegneria Geotecnica Srl – Turin
Sebastiano PELIZZA
Professor Emeritus Politecnico di Torino

The Livio Cosenza 1km-long twin tube tunnel is part of the new road connection between Naples ring road and the Port of Pozzuoli. The tunnel primary function is that of an exodus way from the Pozzuoli city in case of reactivation of bradiseismicity. The new tunnel together with the intermodal plan for the development of the Flegrea Area is part of Peter Eisenman's master project. For half of its length, the tunnel is excavated in a ground that is previously treated by jet-grouting form the surface, while for the remaining part, being built under a populated area of the city, self-drilling jet-injected pipes are used for the umbrella arch and jet-injected self-drilling bolts at the face. A special tunnel section, consisting of a canopy made by directional drilling pipes for isolating the tunnel from the old Cuma emissary will be used. At the time this article (10/2015) is written 1300m of tunnel have been excavated. Advance proceeds from the Northern portal towards the coast. Tunneling works are expected to conclude in early 2017.

1. Introduction

The Livio Cosenza 1 km long twin tunnel is part of the new road connection between Naples ring road and the Port of Pozzuoli. The new road connection together with the intermodal project for the development of the Flegrea Area is part of the master project of the architect Peter Eisenman.

The main objective is the promotion of the Flegrean Area that is characterized by unique natural and archeological resources through a structured framework that organizes all area projects. The elements that characterize the project are: the interconnectivity of the archeological heritage sites, the reclamation of the industrial sites, the requalification of the waterfront area for touristic purposes and finally the transformation of the Port to a touristic one.

Peter Eisenman developed the project following the implementation of the 887/84 – 11-8° Law that deals with the enhancing of the transportation system of areas subjected to "bradisismi" phenomena. According to this Law emergency routes shall be established for evacuating Pozzuoli and Naples historic city centers in the event of reactivation of bradiseismicity.

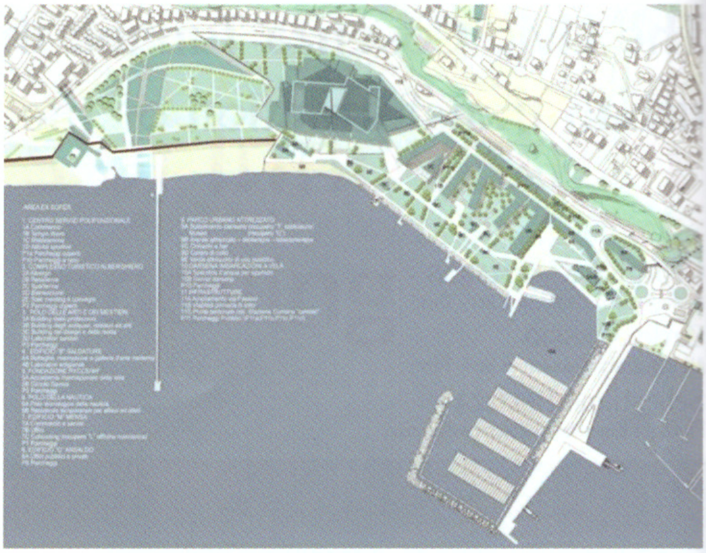
The Livio Cosenza road tunnel, is the first project in the area and highlights the beginning of the Flegrean Area requalification by providing access to the portal area. To the extent that was possible and considering the difficulties in tunnel construction, every effort was made to introduce the tunnel in the architectonic and artistic context of the area. Pozzuoli's plateau that overlooks the seafront consists of loose volcanic sands, unstable upon excavation and for at least half of the alignment underpasses an urbanized area under limited overburden. Along its alignment the tunnel lies along large underground fuel tanks that were built after the 2nd WW that need to be protected for future touristic promotion. Finally, towards the sea portal the tunnel fist overpasses a old emissary tunnel and the local railway where are also situated remains of an ancient roman road.

2. The waterfront project

The Livio Cosenza tunnel provides vital access to the seafront and consequently permits the reclamation of the Flegrean area. This is the reason, together with the bradiseismicity of the area, that priority was given to this infrastructural project.

Eisenman's masterplan defined the roadmap for the promotion of the Flegrea area and consists of the Intermodal Plan, the Rione Terra reclamation, the improvement of the local railways through the connection with the regional metropolitan system, the enlargement and requalification of the port by reclamation of the Sofer- Ansaldo industrial area.

View of the portal area as of today.



Peter Eisenman's project of the waterfront.

Peter Eisenman's project: rendering of the port area.

Peter Eisenman's project: rendering of the waterfront.

Fig. 1 – The transformation of the waterfront area.

The new areal configuration has the objective to transversally overcome the longitudinal barriers present in the area aiming at rendering interconnected the vast historical-archeological resources of Pozzuoli, at large today excluded from the large public. The project transversal elements, apart from improving transportation and pedestrian interconnectivity permit the reconfiguration of the dismissed industrial area and the expansion of the Scientific and Technological park, creating a variety of new public space able to open the city to visitors.

Therefore, key-points of the urban transformation are related to the valorization of the archeological heritage, reclamation of the industrial areas, requalification of the seafront, and transformation of the port to a touristic one.

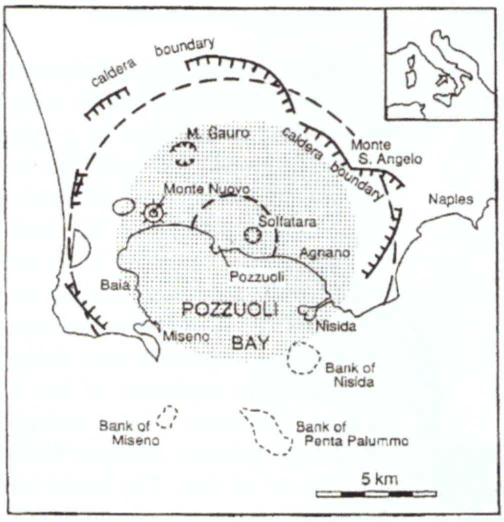
3. The particular context of the project area

A number of unique elements characterize the project: namely the unique seismic activity, the archeological and industrial context, and last but not least the tunnel excavation under an urbanized area. Hereafter a description of these elements.

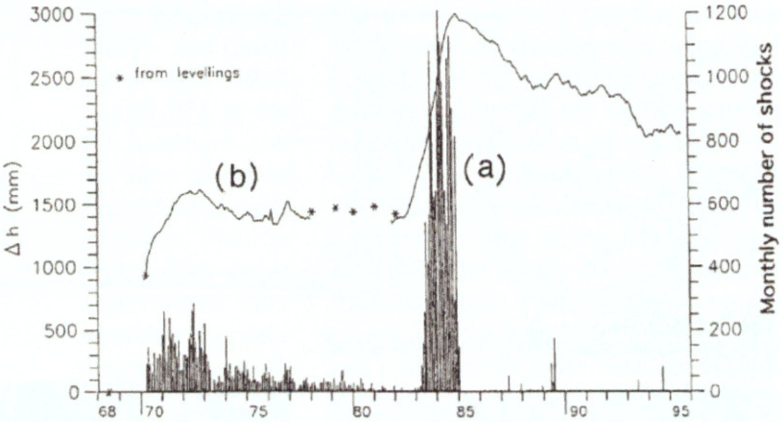
3.1. Bradiseismic activity

Pozzuoli is located along the shore of the Pozzuoli Bay, the western part of the Gulf of Naples and at the center of Campi Flegrei caldera. The secular changes in the height above the sea level of "Serapeo" which is the ruins of a Roman market near the shore at Pozzuoli have been documented from time to time since the Roman period. Such secular changes are named "Bradisismi" which means slow movements due to a particular volcanic activity. The most recent event began as an abrupt upheaval of the ground noticed at the Pozzuoli port in 1969. It was not accompanied with remarkable earthquakes or volcanic eruptions in this district. The upheaval reached a peak in 1973 and after some stagnation, reached another high peak in 1985, and thereafter gradual subsidence is continuing (Figure 2) (Yokoyama, 2006).

The new tunnel, being the principal exodus way in case of bradiseismic activity from the city of Pozzuoli, was designed to bear loads arising from seismic activity. In addition, along the tunnel is foreseen the installation of specific geotechnical

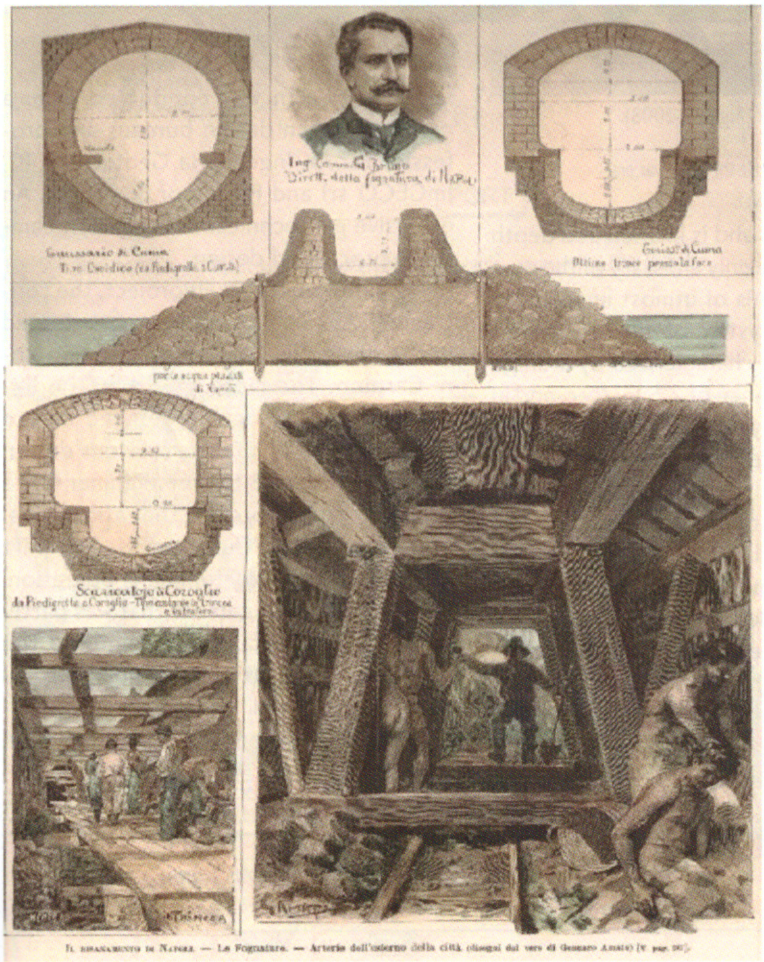


Topographic sketch map of Campi Flegrei. The outer circle indicates the limit of the deformation and the inner one does a contour of 50% of the upheaval at the center. Dotted area (r = 5 km) indicates an assumed area of upheaval in a circular cone centering.

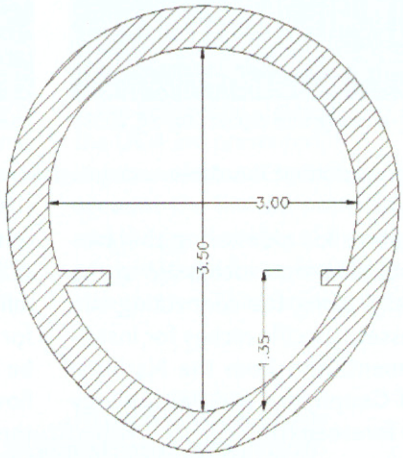


Activities in Campi Flegrei during the period, 1970~1995 : (a) Monthly numbers of earthquakes in Campi Flegrei, (b) Upheaval trend at Pozzuoli determined by mareographic observations (Osservatorio Vesuviano Bradisismo Flegreo. Rapporto Sorveglianza).

Fig. 2 – Bradiseismic activity in the Campi Flegrei (Yokoyama, 2006).



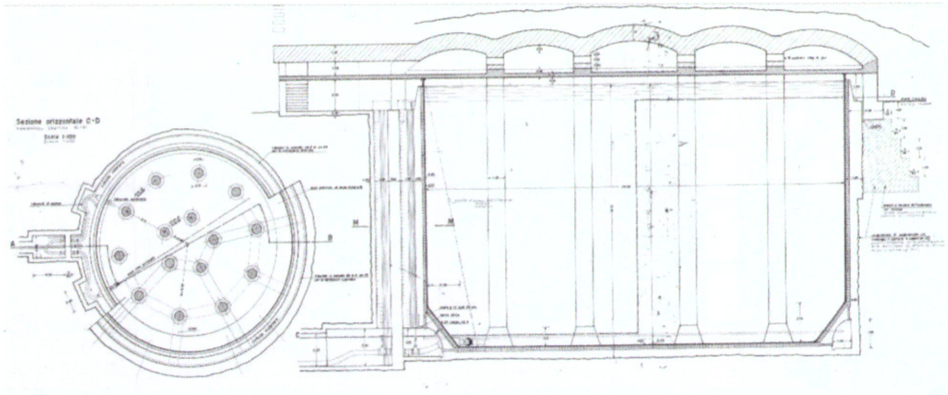
Extract from an old journal.



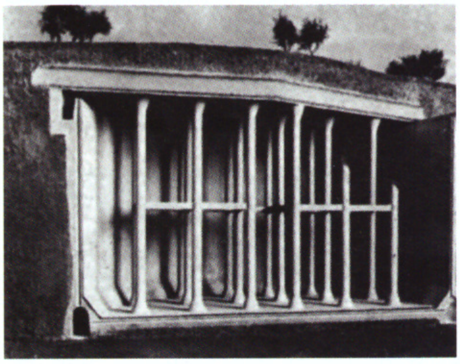
Cross-section at the project area.

Investigations during project phase.

Fig. 3 – The Cuma emissary: old poster depicting project and construction method, cross-section of the emissary at the project area, and photo from investigations conducted during the design phase.



Drawing of the underground tanks (plan and cross-section).



Plastic model of un underground deposit (Argiroffi, 2008).

Internal view of the tank (Argiroffi, 2008).

Fig. 4 – Drawings and photos of 36 m-diameter underground tanks in the tunnel area built the post-war era.

instrumentation for monitoring the evolution of possible movements along the tunnel. Finally, along the connecting two tubes bypasses, specific niches for installing instrumentation from the National Institute of Geophysics and Volcanology (INGV) are foreseen.

3.2 The Cuma emissary

The Cuma emissary has a length in the range of 13 km and was constructed in the end of the 19th century. Along it alignment it collects the diluted wastewater from Naples and Pozzuoli. In the project area it has an ovaloid cross-section with internal dimensions 3x3.5 m (wxh). It is constructed out of tuff blocks and is located at a depth of 33m. Being the only emissary of the overall Flegrean area is of utmost importance for the sewage system of Naples, cannot be interrupted, is characterized by average flow rates in the range of 2.5 m^3/sec, and in the event of heavy rainfalls eruption events have been reported.
During the design phase an extended campaign of investigations was done consisting of core drillings, laboratory tests, on specimens of the tuff lining of the emissary, as well as borehole video inspection. These investigation aimed at defining the consistency and the thickness of the lining (as well as the presence of voids in the ground surrounding the old tunnel).

3.3 Underground fuel tanks

In the project area exist 5 dismissed 36 m diameter fuel tanks built in early fifties connected to each other by a network of adits. The reinforced concrete tanks lie next to the tunnel, one of which is underpassed by the tunnel. The tanks have a height in the range of 15 m and were designed by the famous Italian engineer Pier Luigi Nervi as tanks for depositing fuel for navy ships and were designed to withstand the explosion of two 500 kg bombs. The dome of the tanks is supported by columns and can hold up to 30,000 m^3 of fuel. The tanks were the result of secret experimental and theoretical research and is an important historical monument of Italian engineering during the post-war period. Such tanks can be found in Sicily and Pozzuoli.

4. The tunnel design phase

Detailed design was conducted from a group of Italian design bureaus and professionals: AK Ingegneria Geotecnica, IC, ImGECO srl and Professor S. Pelizza. An extensive geotechnical investigation campaign proceeded design.
Being a design-and-built project, the contractor SABESA SpA actively participated in the design by Luigi Paieri and Giovanni Carpino. The most important modification made during the detailed design phase with respect to the previous design was related to the tunnel alignment: the original design foresaw that the tunnel underpassed the Cuma emissary. Apart for being a very risky tunneling operation, it resulted in an alignment that was partly under the water-table and required the continuous operation of a pumping system in the tunnel.
The project alignment has a sinusoidal

Tab. 1 – UG4 geotechnical parameters.

Geotechnical unit	Description	γ [kN/m^3]	c' [kPa]	ϕ' []	E [MPa]	ν [-]	K [m/s]
UG4	Volcanic products and deposits of marine environment or of transition consisting predominantly of sands: pyroclastites, cinerites, pumice and marine sands with pumice and scoria	16-20	5-40	33-38	50+5.0×depth	0.33	1.9e-5

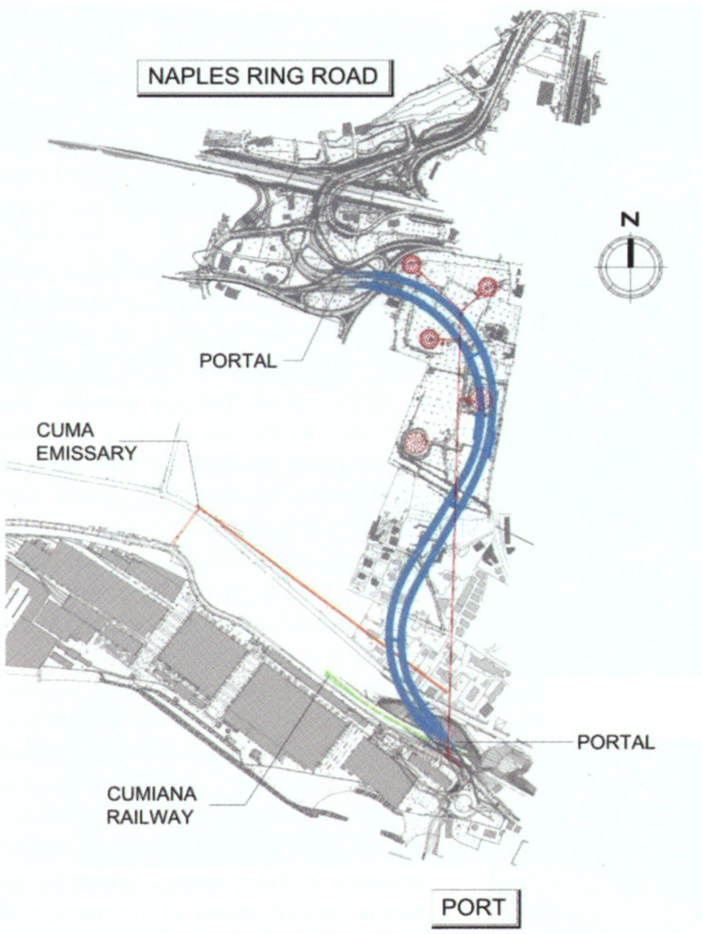


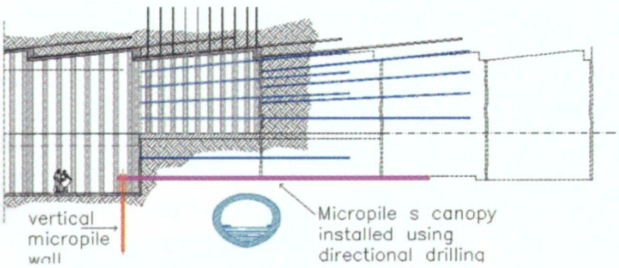
Fig. 5 – Planview of the project with the undergound fuel tanks, connecting adit and the Cuma emissary

geometry, and a general orientation north (Naples ring road) – Sud (port) and a length of 928 m and 973 m for the southern and northern direction respectively and a minimum 1400 m radius. Two major constraints were considered in defining the alignment: overpass the Cuma emissary and underpass the Cumiana railway located at the seaside portal. This resulted in an alignment that has a maximum longitudinal slope of 6.6% and a maximum project velocity of 60 km/h. The tunnel inner section consists of two lanes. A 45 m long emergency lane parking section, one vehicle and two pedestrian by-passes are also foreseen.

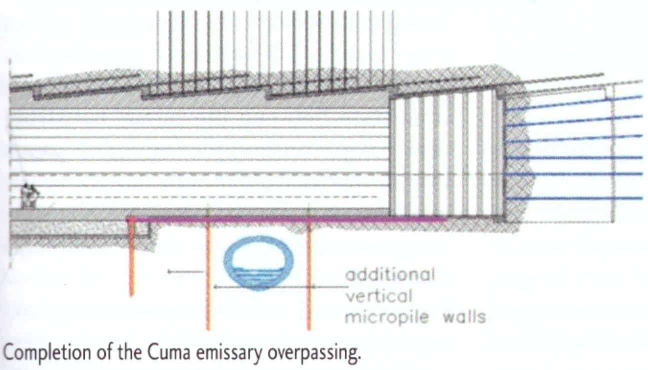
The tunnel alignment together with the junction with Naples ring road is provided in figure 5. In the following paragraphs the geotechnical context and details regarding the excavation methods are discussed.

Geotechnical site investigations started in 2008 during the initial project phases. The last campaign, that for the detailed design, was completed by July 2012 and included 10 boreholes for a total length of core recovery of more than 300 m. Lefranc, SPT and pressiometer tests were conducted, as well as samples recovered from the boreholes were subjected to direct shear and triaxial tests. Together with the results of previous site investigation campaigns that included geophysical investigations as well an important quantity of stratigraphic data and geotechnical data a detailed geologic and geotechnical profile was compiled. For most of it length the tunnel is excavated within the so-called geotechnical unit UG4 consisting of fine and coarse sands. In table 1 the geotechnical parameters adopted for the UG4 are presented.

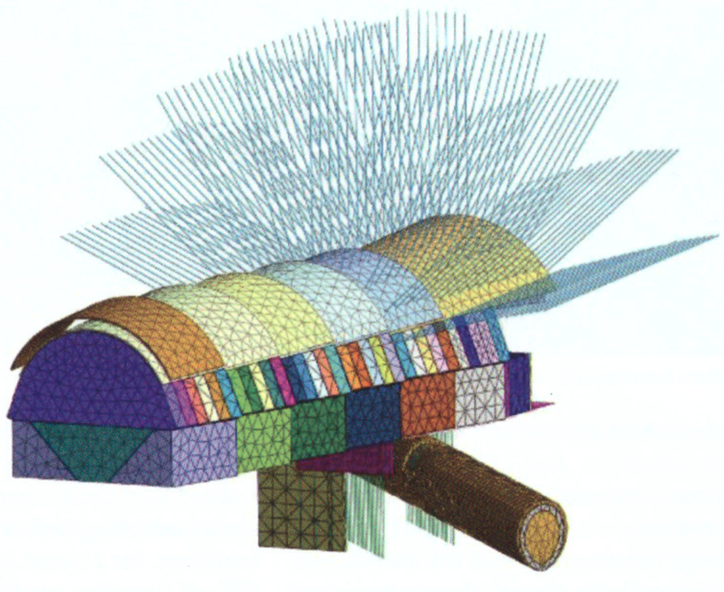
In terms of tunnel section, and taking into account the limited overburden (<30 m) and the good quality of the sands as a subgrade material it was decided to adopt a flat slab section. This choice apart from reduc-



Installation of the horizontal micropile canopy.



Completion of the Cuma emissary overpassing.



3D Finite element modelling.

Fig. 6 – Tunneling methodology for the Cuma emissary overpassing (representative sections and finite element model used for dimensioning).

Northern tunnel portal towards Naples ring road.

Southern tunnel portal towards the port.

Fig. 7 - Rendering of the tunnel portals.

ing muck material, simplified construction procedures.

Taking into account that for almost half of its length the tunnel is excavated in an area free from surface impediments a consolidation scheme based on intersected jet-grouting 2 m in diameter columns to be realized from the surface was defined. The aim of adopting such a technique was to transform, for at least half of each length, difficult tunneling conditions characterized by unstable face to a rather simple tunnel section consisting of only steel sets and shotcrete (section type C1). For the remaining part of the tunnel where dwellings persisted in the surface a top heading and bench tunnel section (section C2) was defined characterized be a self-drilling tubes jet-injected for the pipe umbrella and jet-injected self-drilling bolts for front (the so-called Pelizza-2 method, Pelizza et al., 2015).

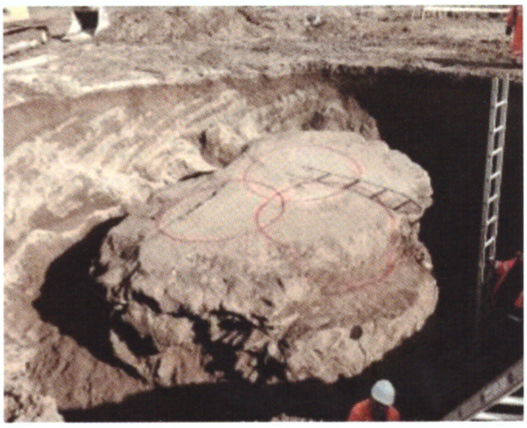
The design principles for the Cuma overpass (minimum space between tunnel slab – Cuma extrados: 1 m) top-heading and bench section were the following: reduction, to the extent that it is possible, the disturbance to the old emissary from the construction of the tunnel, elimination of the geotechnical loads acting on the tunnel to the old structure and a tunnel section able to withstand hydraulic loads in the event that pressure build-up in the emissary. The tunnel section is a variation of the C2 one and is characterized by:

- a canopy consisting of horizontal micropiles installed between the future tunnel slab and the Cuma extrados drilled from a trench before the Cuma emissary. The canopy is founded on vertical micropiles installed on northern side of the emissary. In this manner, a bridge structure is created aiming at the transfer of construction and working loads on the ground surrounding the old emissary;
- transfering tunnel loads to the ground away from the emissary. In this sense, a temporary invert and most important radial bolts are installed at the top-heading crown before the bench excavation are adopted. The primary support sections is closed by a steel set and placed shotcrete along the excavation bottom. Finally, before casting the tunnel lining slab an additional set of vertical micropiles is installed along the sides of the Cuma emissary.

Taking into account the complexity of this project node, 3D numerical modeling was implemented (MIDAS GTS) for defining the interaction between the tunnel construction, long-term behavior and the Cuma structure as well as dimensioning the structural elements consisting of the solution. In figure 6 the 3D finite element model is presented.

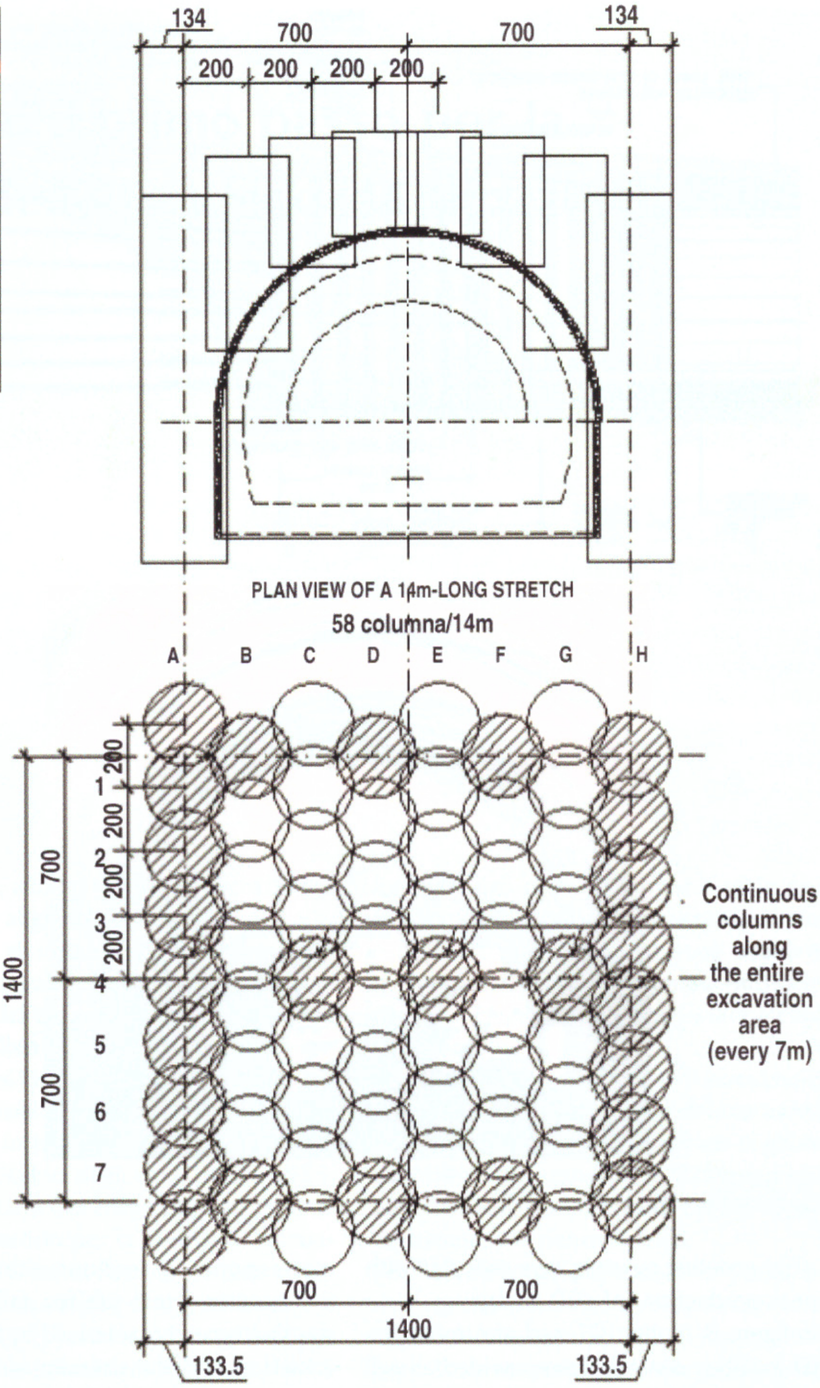
Regarding the northern portal and taking into consideration that for the first part of the tunnel jet-grouting would be used, all excavations were supported by

Northern Portal site where jet-grouting was used to support excavation slopes.



Jet-grouting test site columns.

Excavation of section C1.



Section C1: Jet grouting scheme.

Fig. 8 – Northern portal, jet grouting test columns and section C1 excavation scheme.

jet-grouting walls. Special attention was paid to the environmental integration of the northern portal for which a sail-type of geometry was adopted for the artificial tunnel. The presence of the local railway line that is proceeded by the steep Starza plateau from which the tunnel exits created a quite demanding project configuration that required simple construction technologies. It was decided to support excavations by micropile walls and a top concrete slab.
In figure 7 portals rendering is provided.

5. The construction phase

Construction started in early 2014. Following a jet-grouting test site, the foundations subcontractor TREVI SpA, confirmed the use of 2.7 m drilled at 2 m center-center distance. The result was optimum in terms of geometry (<1% average vertical deviation), in terms of strength (average value: 8.3MPa) and cement consumption (<400 kg/m^3). In total 45000 m of jet grouting columns were drilled. A total of 26000 m

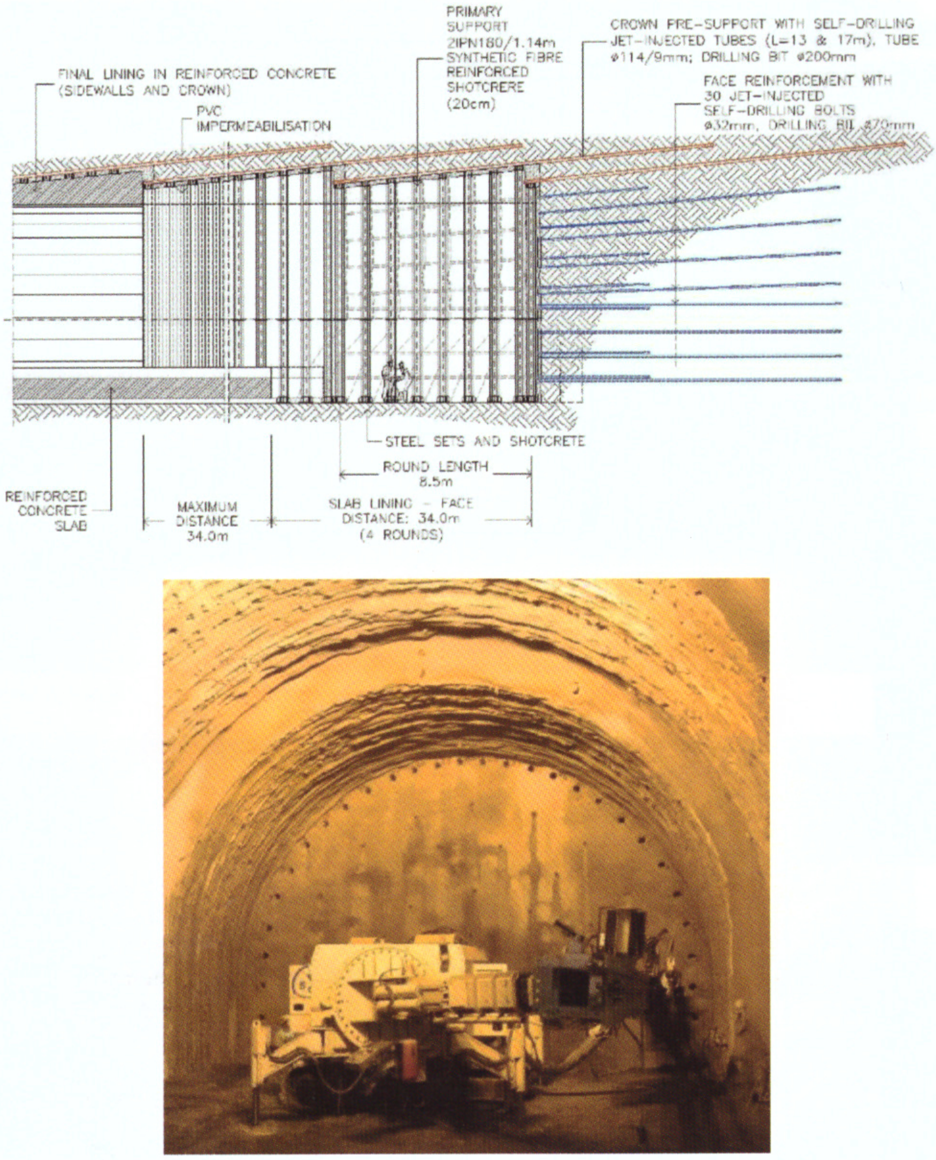


Fig. 9 – Section C5 m.

of jet-grouting columns were executed with peak productions of 200 m/day.

In figure 8 section C1 and photos of the jet-grouting campaign are provided as well as a photo of the northern portal. In addition, steel ribs used in the beginning of the excavation were soon replaced by 4-rod triangular lattice girders aiming at a primary support system that was in complete contact with the excavated ground. Average advance rate in the jet-grouted ground was 4.5 m/day.

There were areas along the foreseen tunnel length where the C1 was to be applied that due to archeological excavations it was not possible to execute the jet-grouting from the surface. The corresponding sections along the tunnel became a test-site for defining a new section type characterized by full-face excavation and the pre-support measures (pipe umbrella and face reinforcement with jet-injected self-drilling pipes and bolts for the crown and face, respectively). This experimentation was combined with an extensive monitoring scheme in the surface and underground as well as pull-out tests for the self-drilling bolts. Based on the actual excavation-ground behavior as well as monitoring results a new section was defined that gradually replaced the C2 section. The new section was named C5m and consisted of: crown and sidewalls pre-support by jet-injected self-drilling pipes and bolts of increased length in the crown with respect to C2 section, an increased number of jet-injected self-drilling bolts at the front and the closing of the primary support section by steel sets and shotcrete installed at the face. C5m excavation section and a photograph of the front are provided in figure 9. It takes, on the average, 6 days (three shifts per day) to excavate a 8.5 m of tunnel.

To accelerate installation of lining reinforcement a prefabricated lattice girder structure was adopted for all of the sections crown final lining. At the time this article (10/2015) is written 1300 m of tunnel have been excavated. Advance proceeds from the Northern portal towards the coast. Tunneling works are expected to conclude in early 2017.

Acknowledgments

The tunnel is named after the founder of COPIN, Prof. Livio Cosenza, an exceptional person who dedicated his life for Pozzuoli and who unfortunately will not be able to see the completion of this project. Special thanks deserves Aldo Scarantino who follows all administrative project-related tasks that are vital for the project. The works advancement is a merit of Copin's current technical Director Marco Porta and of his stuff David Giorgetti, Carlo Crestini amongst others. Finally, the Project Engineer Mauro di Pace responsible for the correct execution of the works is specially acknowledged.

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La Fase Costruttiva

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General Contractor: **COPIN DUE S.p.A.**

Affidataria: **SABESA S.p.A.**

Responsabile Unico del Procedimento: Ing. Agostino Magliulo

Direttore dei Lavori: Ing. Mauro Di Pace

Direttore Tecnico: Ing. Marco Porta

Consolidamenti dall'alto: **TREVI**

Realizzazione galleria: **ATI TECHNOSCAVI, SCF, OLIDRAG, TECNOMANTO**

Monitoraggio geotecnico: **I&C Italia**

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