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TUNNELS AND UNDERGROUND CITIES: ENGINEERING AND INNOVATION MEET ARCHAEOLOGY, ARCHITECTURE AND ART

Società Italiana Gallerie
Italian Tunnelling Society
Line C in Rome: San Giovanni station

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• Line C project in Rome with particular reference to the stretches presently open to the public and the T3 stretch under construction

• The main construction phases and building techniques used in San Giovanni station for responding to the various problems concerning geology, archaeology and the surrounding buildings. In fact, the phases for building this station were heavily constrained by the archaeological findings that required an overall revision of the internal design of the station.

• The main aspects of the tunnel excavation under the foundation slab of the existing Line A San Giovanni station using the ground freezing method with a summary of the main results of the monitoring system installed in the existing station.
The construction of Line C was assigned in February 2006, under a turn-key basis, to Metro C which is the General Contractor, led by Astaldi, charged with the design, the construction, the work supervision and the supply of rolling stock for Line C of Rome Underground:
Line C is Rome’s third underground line. Once completed, it will cross the city from Northwest to Southeast, for a total length of about 26 km and 30 stations. At present 22 stations and 20 km of line are open to the public.
T3 stretch under construction

- 2 stations: Amba Aradam, Fori Imperiali
- 2 ventilation shafts: Shaft 3.3, Shaft 3.2
- Length: 2.8 km
- Depth: 30 ÷ 60 m
San Giovanni station: the first archaeological station in Italy
San Giovanni Station
San Giovanni Station

Longitudinal section with Line C and Line A

LINE C  San Giovanni Station
Length 140 m - Depth 35.00 m

LINE A

INTERCHANGE

LINE A PLATFORM

LINE C PLATFORM

LINE C TUNNELS
UNDERCROSS
LINE A STATION

The station consists of 4 internal slabs: two floors are open to the public for the interchange between the two Lines and the other two floors include ventilation and electrical systems.
San Giovanni Station – The archaeological surveys

The archaeological surveys in San Giovanni job site started in 2007 with the execution of about 500 boreholes.
The results of the archaeological surveys showed an unexpected archaeological layer distributed down to a depth of 18 m with a water table at about 8 m below ground level.

The archaeological Ministerial Office of Rome imposed the following construction constraints:

1. impossibility of performing consolidations from ground level without prior archaeological excavation;
2. need to carry out all the excavations by archaeological method down to “virgin” ground.

These obligations required an overall review of the Line C design in the historic centre of the city of Rome, starting right from San Giovanni station, to safeguard the archaeologically sensitive layers.

The results were reported in a document named “Prontuario” - “handbook”. This document sets already in the design phase with the Ministerial Office the excavation methods and the organization of the archaeological activities ensuring the respect of performance times and safeguarding the archaeological findings. This is the first example in Italy.
San Giovanni Station – The archaeological surveys

A plano-altimetric variation of the Line was required between Amba Aradam station and Lodi station, right before San Giovanni station. The TBM tunnels were deepened under the archaeological layers and tunnels excavated with the traditional method were introduced in order to run under the existing station.

The excavation depth of San Giovanni station was increased to run under the existing Line A station.
The excavation area of San Giovanni station was reduced to mitigate the archaeological risks.
San Giovanni Station: The «modified cut and cover» method

The study of the new execution phases were heavily constrained by the archaeological findings and the “cut and cover method” was adapted to the restrictions of the archaeological excavation, taking advantage of the use of the internal slabs to support the perimeter diaphragm walls during the excavation. This method has been called “modified cut and cover method”.

- At the beginning road traffic is diverted and diaphragm walls are realized
- The archaeological excavation starts up to 3 m under the first slab
- The first slab is built with precast structures, so the road traffic can be opened again
- During the excavation all slabs are built with precast structures up to the slab foundation when the excavation level is about 3 m under each slab
- At the end of excavation the internal walls are realized to complete and waterproof the box
The excavation is about 30-35 m below the ground level, it reaches the layer of sand and gravel (SG) that is a soil with a high permeability (5E-4 m/s).

The thickness of the perimeter diaphragm walls is 1.2 m and they are about 56 m in length reaching the layer of Pliocene clays to ensure the waterproof of the soil during the excavation.
All the internal slabs were realized with **self-supporting precast structures** to reduce the use of temporary supports because **the archaeological limitations forbade the slab construction with the setting of the structures above the soil with archaeological risk.**
50,000 m$^3$ of soil with archaeological method were excavated in San Giovanni job site and 40,000 archaeological remains were found.
The most important archaeological remains was a **big reservoir of late Roman age** with dimensions 35x70 m found at a depth of about 15 m below the ground level between the second and the third internal slabs.
The reconstruction of the area carried out by the Archaeological Ministerial Office
At the end of the archaeological excavation, the **Archeological Authority got to change San Giovanni station design** in order to add value to the archaeological context.

Thus **Metro C designed and realized a permanent archaeological exhibition** with the cooperation of the **Architectural Department of University “La Sapienza” of Rome**.

This design was based on a **long tale and projection in the history of Rome** using many graphic elements and some special exhibitions of a short selection of remains.

**High perceptibility, fast comprehension and visual comfort** were three important characteristics of the design.
San Giovanni Station: The archaeological exhibition
Tunnel excavation under the existing Line A station
Line C tunnels run under Line A station and they were excavated with the ground freezing method in order to reinforce and waterproof the soil during tunnel excavation. In fact, the presence of the foundation piles of the existing station did not allow to use a TBM machine.
The excavation of Line C tunnels interacted with the foundation piles of existing station.

San Giovanni Station: The interaction with Line A station
Placed around each tunnel to be excavated were 36 freeze pipes circulating refrigerants and 15 temperature probes for the continuous and real-time monitoring of the development of the ice wall.

The average design temperature is -10 °C and the ice wall to be made around each tunnel had a thickness of about 80 cm at the sidewalls and approximately 3 m in invert because of the presence of foundation piles.
The phase of guided horizontal drilling was characterized by many operating difficulties due to:

- the lack of homogeneity of the soil and the discontinuity within the sand and gravel layer
- the presence of the magnetic field generated by the operating Line A

The directional drilling, magnetically guided, proved ineffective because deviations up to 4 m were recorded.

About 6 months of field testing led to choose a Wassara type water-powered hammer at the hole bottom with the recording of deviations at the end of each drilling.

Because of this unconventional horizontal drilling, a new freezing mask was studied and the inter-axes between the freeze pipes had to increase:

- the vertical inter-axes were increased up to about 1.6 m.
- the horizontal inter-axes were increased up to about 3.7 m.

The new freezing mask involved an increase in the number of freeze pipes by about 50% with an increase in the nitrogen and in the time needed to reach the ice wall thicknesses provided for in the design.
The complexity of the design geometries required the use of a mixed system with nitrogen, in the initial phases of freezing, to reduce the time required to form the ice wall and brine in the maintenance phase to control the expansion of the ice wall with time, thus reducing the deformations induced on the existing slab of Line A.
San Giovanni Station: Temporary metal deck

While the tunnels were being built, a temporary track support system was installed at the platform level of Line A station. It was constituted with a continuous metal deck with two 20 m long spans and 3 foundation plinths.

- Number foundation plinths: 6
- Number micro-piles: 72
- Length micro-piles: 12 m
- Weight metal deck: 100 ton
- Transversal section metal deck: 2500 mm
- Height metal deck: 560 mm
- Thickness metal deck plates: 45 mm
San Giovanni Station: ground freezing method
San Giovanni Station: ground freezing method

- The duration of the freezing phases was **20 days** each tunnel using about **1,400 l/m³** of nitrogen for a total consumption of about **6,000,000 l** of nitrogen.
- The duration of the maintenance phase was **about 60 days** each tunnel used for the excavation and the permanent lining realization of the tunnels.
- The duration of the defrosting phase was **about 6 months** each tunnel.

5 foundation piles of existing Line A station **were re-profiled to remove the interference with the track section**
San Giovanni Station: The monitoring system

The existing San Giovanni Line A station was always open to the public during the tunnel excavations and an important geotechnical and structural monitoring system was developed to control the movement of existing buildings.

The movements of the slab were monitored using **18 settlement gauges placed along 3 alignments** of the bottom slab of Line A, parallel to the rails.
San Giovanni Station: The monitoring system

The volume variation of water in the passage from the liquid to the solid state exerted pressures on the existing station foundation slab with important liftings recorded by the monitoring system without any structural problems for the existing Linea A station.

- The displacements of the diaphragm walls are negligible.
- The liftings recorded on the pillars at the level above the Line A platform were on the order of 17 mm.
- The liftings recorded by the settlement gauges placed on the slab were on the order of 50 mm along the central alignment and 20 mm along the external alignments.

The liftings were totally recovered at the end of the long term effects.
Take away points

• The excavation of San Giovanni station represented an unique opportunity for new important acquisitions about the history of Rome, in fact the archaeological excavations rarely reach such a depth in urban areas.

• The construction technologies used for building this station were heavily constrained by the archaeological remains. These findings required an overall revision of the Line C’s design in the historic centre of Rome, starting from the San Giovanni station, to safeguard the archaeological layers.

• The permanent exhibition inside the station is the first example in Italy to visualize the history of the site with a "time travel" that started with our times at the ground level down to the Prehistoric Times.

• Tunnel excavation under the existing San Giovanni Line A station with the ground freezing method was a very challenging performance because of the interaction with Line A station that was always open to the public during the tunnel excavation.