NAPLES UNDERGROUND

Line 1 - Section between Dante and Centro Direzionale Nord

**BACKGROUND**

The lower section (Dante – Centro Direzionale Nord) of line 1 of the Naples metro, currently under construction, will create effective links between important districts of the city passing through Vomero, Piazza Municipio and Corso Umberto to then reach Stazione Centrale and Capodichino Airport (figures 1 and 2). The construction of the running tunnels (two tubes, side by side with an inner diameter of 5.85 m and a distance between centre lines of approximately 11 m.) and of five stations (Toledo, Municipio, Università, Duomo

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**Main characteristics of the running tunnels (twin tube tunnel)**

- Length: 3,900 m
- Diameter of excavation: 6.75 m
- Outer diameter of segment ring: 6.45 m
- Inner diameter of segment ring: 5.85 m
- Thickness of segments: 0.30 m
- Minimum actual radius of curvature: 180 m
- Design radius: 150 m
- Length of segment ring: 1.20 m
- Number of segments per ring: 6 + key

**Main characteristics of station platform tunnels (4 tunnels for each station)**

- Length: 900 m
- Diameter of excavation: 11 m
- Lining thickness: 0.80 m

**Client:** City of Naples

**General contractor:** Metropolitana di Napoli S.p.A.

**Design and project management:** Metropolitana Milanese S.p.A.

**Design of underground works:** Rocksoil S.p.A. (Milan)

**Start of works:** January 2002

**Cost of civilian engineering works:** €322,000,000
and Garibaldi) located along the route required the typical problems of tunnelling in urban areas to be studied and solved on the basis of the specific conditions of the Naples terrain. Surface subsidence had to be limited to avoid damage to surface buildings, the safety of operations had to be maintained working under shallow overburdens and under the water table and so on. The problems were solved by employing some of the most advanced and reliable construction technologies available.

**GEOLOGICAL AND GEOTECHNICAL CONDITIONS**

At Piazza Dante the route starts to pass mainly under the water table through pyroclastic materials such as pozzolans and tuffs and then, in the section after Garibaldi station, through sandy, silty deposits (Fig. 3). The pozzolans and tuffs have a chaotic structure with an ash-vitric matrix and are separated by a transition stratum which is generally more porous named “cappellacio” or Neapolitan yellow tuff. The stonier part of the tuff is fractured subvertically along the pathways taken by the gas with which it was impregnated escaping, a phenomenon known as “scarpine”, formed following the slow cooling of the pyroclastic mass.

In Via Toledo the free surface of the water table runs on average at an altitude of 4.5 m. above sea level and tends to fall gradually towards the coastal areas (2.5 m. a.s.l. in Piazza Garibaldi).

The water moves along a low gradient in the surface ground which has a higher degree of permeability ($10^{-3} - 10^{-5}$ cm/s) than the underlying stratum of tuff. The primary permeability of the latter is low but the secondary permeability is closely related to the degree of fissuring.

From a geotechnical viewpoint the pozzolans, sands and ashes are loose materials which need to be adequately confined during tunnel advance.

Although the tuff has good strength properties ($c = 0.8 - 1.0$ MPa, $\varphi = 28^\circ$), as has been said there is widespread fracturing in it with an unpredictable geometry and considering the high water heads in play (up to 3 bar), excavation must be performed with appropriate flood protection.

**RUNNING TUNNELS**

From a design viewpoint, the vertical geometry of the running tunnels was designed so that they run for their entire length through the stony yellow tuff formation characterised by good strength properties. This alignment avoids the need to excavate the loose ground above, where maintaining surface subsidence within acceptable limits for the safety of surface constructions would have been exceedingly more difficult. Furthermore, apart from the initial section located immediately after Piazza Dante, the tunnels will be completely under the water table. The maximum water head (approximately 30 m. at track level) is under Piazza Garibaldi.

Even if the permeability of the tuff is low ($10^{-6} - 10^{-8}$ cm/s), there is still a real possibility of serious flooding in those sections where the stony overburden is shallower, or where subvertical fractures (“scarpine”) are present in the rock. With water flowing in through the loose ground in
the overburden there is a very high risk of it dragging solid material with it and causing serious surface subsidence. The phenomenon is badly well known in Naples, the result of cavities scattered in the subsoil and the ease with which the loose pyroclastic materials erodes. To protect against this danger, a completely mechanised system of excavation was adopted which employed the following:

- two EPB shields (one per tube) with a diameter of 6.75 m.;
- the immediate lining of the walls of the excavation with the placing of an impermeable lining of prefabricated concrete segments erected inside the shield and backfilled with mortar outside the shield using extruded concrete.

This method of operation guarantees effective and immediate confinement of all the excavated surfaces of the tunnel during construction:

- at the face, by counterbalancing the hydrostatic pressure and the earth pressure on the head of the shield;
- around the cavity, by erecting an impermeable lining of prefabricated segments made immediately active by using extruded concrete to backfill the space which inevitably remains between the ground and the segments (“loss of volume”).

The method minimises the “losses of volume” during tunnel advance, eliminates the risk of potential flooding and last but not least provides full control of surface subsidence.

- the water table is not affected in any way at all because the pressure of the water at the face is constantly counterbalanced by the hydrostatic confinement systems of the machine;
- the materials employed are not polluting; the ground excavated is mixed with water and special additives and then conveyed outside the tunnel where, because of its intrinsic properties, after separation from other elements it is used in the construction of other civil works (embankments, raised areas, etc.).
The standard prefabricated segment ring lining employed was horizontally truncated in shape and consisted of six segments plus the “key” segment (figures 4a and 4b, photo 1), all 30 cm. thick and jointed one into the other. The very special and carefully designed shape makes it possible to follow the theoretical tunnel alignment with an excellent degree of approximation, by simply assembling different types of ring in sequence as required each time. Water proofing is guaranteed by means of seals fitted continuously along the outside of the segments.

SHAFTS AND STATION TUNNELS

Space on the surface is generally limited and problems with traffic circulation resulted in the design of a standard structure common to all stations.

The design consists principally of rectangular shafts, 20 x 45 m. approx., sunk down to a depth of 35 – 50 m. and centred over the running tunnels (figures 5a and 5b, photo 2), except for the Toledo station for which the shaft was placed to the side of the running tunnel since it was impossible to centre it over the alignment. These tunnels are constructed with a larger cross section (55 sq. m. of inner diameter) to house the station platforms running for around fifty metres in both directions from the shafts.

Given the poor geomechanical properties of the ground to be excavated and the problems of advancing under the water table, it is essential, before the start of any excavation, to design a confinement perimeter structure for the construction of the shafts which gives guarantees against inflows of water. It consists of flat panel diaphragm walls excavated using a hydro-cutter (photo 3). The perimeter diaphragms are braced by the concrete slabs of the station floors which are constructed as the excavation reached the depth of each floor. Their weight is borne by special transverse elements of the diaphragm. The bottom of the shafts is waterproofed by reinforcing the ground for a sufficient thickness with high pressure injections of cement and chemical mixes.

Finally, construction of the station tunnels starts from the shafts with a cross section of 55 sq. m. The crown generally passes through materials in a transition zone where the lower tuff stratum comes into contact with the overlying pozzolans and/or sands, when it did not actually pass directly through the latter. The safety of excavation work is achieved by reinforcing the band of ground around the future tunnel and making it impermeable using freezing techniques. This is performed using a brine (calcium chloride) system, by inserting freezer pipes into holes drilled horizontally from inside the shafts (photo 4).

The presence of a frozen ring of ground around the excavation (temp. -20 °C, 2 m. thick approx.) guarantees the safety of the work and prevents any inflow of water into the underground works.

The station tunnels are driven full face, using a roadheader, followed by the placing of a preliminary lining, water proofing and a final lining in concrete with the ring closed with a tunnel invert. Once the civil works are finished, and that is after adequate confinement of all the walls of the excavation, ground freezing stops.

STATE OF PROGRESS OF WORKS

The Garibaldi, Università, Municipio and Toledo shafts have been sunk so far. Ground freezing has been performed on one tube of the platform tunnel for the Garibaldi station, while drilling for the freezer pipes is in progress on the other stations. The two running tunnels started from the Brin shaft (Fig. 2) and have reached the first station after approximately 1.000 m. of tunnel advance.