The Genoa Underground: construction of the Principe-Caricamento-Le Grazie stretch

Prof. Ing. Pietro Lunardi
Lunardi's Geo-engineering office, Milan, Italy

Dott. Ing. Giovanna Cassani
ROCKSOIL S.p.A., Milan, Italy

ABSTRACT: The Principe-Caricamento-Grazie stretch of Genoa Underground System (twin tunnels, 1400m long), currently under excavation with an EPB shield in heterogeneous ground (loose material, marly-clay and marly-limestone), under water table and very close to the seaside. Each single track tunnel has an excavation diameter of 6.10 m and an internal diameter of 4.9 m. The tunnel overburden varies from 6m to 12 m, and the route heavily interferes with existing town buildings. According to the design work carried out by Rocksoil S.p.A., Milan, the tunnel lining consists of a first ring of pre-cast concrete segments and of a second cast lining. The two rings are separated by a waterproofing PVC membrane. Ground treatment by cement and chemical grout injections has been used to protect nearby building and Genoa Fly-over Road foundations. MPSP injection system and jet-grouting technologies have been used for these treatments on the sides and around the cavity. A large monitoring program has been applied to control tunneling in urban area.

1 INTRODUCTION

The Principe-Caricamento-Grazie stretch of Genoa Underground System, consists of twin tunnels, at present under construction in advanced phase. It is the most significant stretch of the entire line, both for its connection with urban improvement areas, and for the particular geological and hydrogeological conditions of the materials affected by excavation.

The stretch under construction will connect Principe Station to Caricamento Square, San Giorgio Palace and the exibition area of Aquarius and Porto Antico. The tunnels are positioned in a heavily urbanized area, under the water table, near the sea, through highly heterogeneous matherials.

2 GEOLOGICAL AND HYDRO-GEOLOGICAL CONDITION

The twin tunnels are situated mostly within pliocenic stiff clays and marly-clays, as well as for relevant stretches within marly-limestone bedrock. Above these layers, a layer of fill material with a maximum thickness of 10 m, due to anthropogenic action, is encountered. The overburben varies up to about 12 m, and in some cases fill material affect tunnel sections in crown.

The two tunnels runs along the seaside, mostly under sea level, with a few meters water head.

3 TUNNELS EXCAVATION AND LINING

3.1 *EPB Machine excavation*

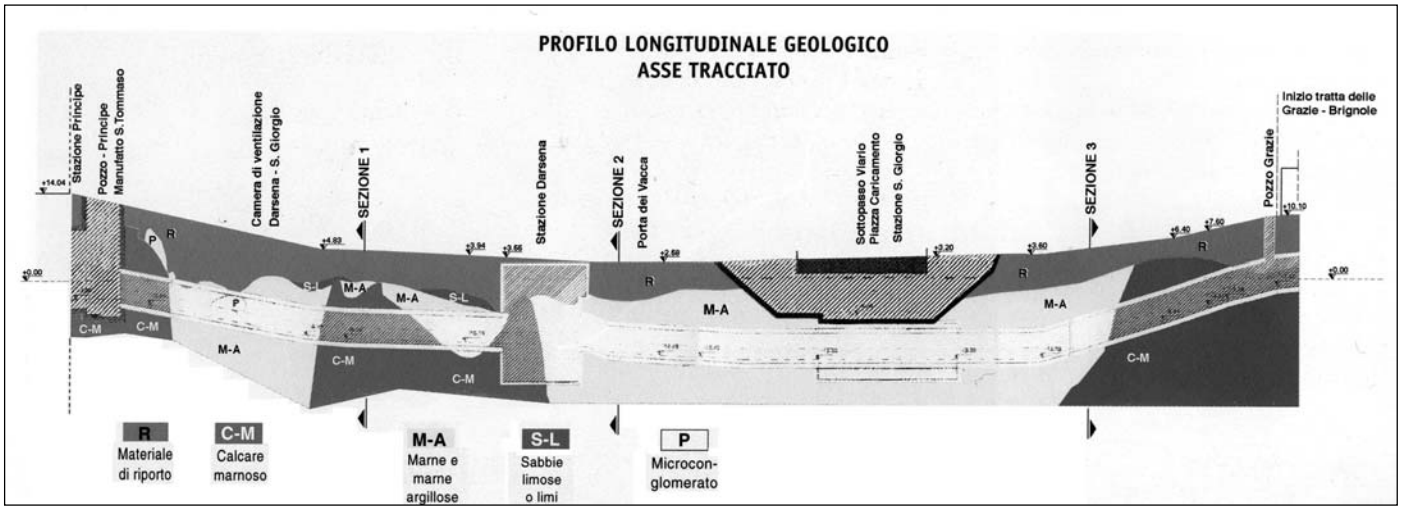
The geotechnical characterisctics of the ground to be tunnelled, the water table presence, the shallow overburden and the presence of tall ancient buildings and of the Genoa Fly-over Road along the route, lead to choose TBM tunnel excavation method. An EPB (Earth Pressure Balance) Machine has been employed, which is able to control the ground settlement and disturbance, acting on machine settings on earth pressure in the excavation chamber at the tunnel face, varying from active to at-rest pressure, and on back-filling pressure behind the pre-cast segment lining. In this way, it is possible to re-compress the loosened ground around the cavity.

The tunnels were each driven from two shafts, dug at the opposite ends of the stretch.

The tunnel excavation section has a 6.10 m diameter, and the tunnel lining, made of a sequence of pre-cast concrete segment rings, is closely installed at the tail of the TBM shield.

3.2 *Grouting*

Previous tunnels excavation, ground treatment by cement and chemical grout injection and by jet-grouting technology has been provided, as a protec-



tion of buildings foundation and Genoa Fly-over Road pillars foundation along the tunnels route. Grout injection has been carried out according to MPSP (Multiple Packer Sleeved Pipe) system.

Further ground treatment has been provided in order to make the ground encountered by the TBM homogeneous in term of strength and stiffness, along the transition zones between clay and limestone layers. Locally, the thin wall of the ground between the two tunnels has been improved by grouting.

3.3 *Lining*

The tunnels lining consists of a sequence of pre-cast concrete segment rings, each one about 1.20 m long and 30 cm thick. The lining ring has been thought as a "universal ring", which is shaped according to the characteristic layout parameters. Installing a sequence of rings, positioning the following one suitably rotated of a fixed angle respect to the previous one, it is possible to follow continuously the plan-height tunnel route layout. The joints between segments of the same ring are plane; segment rings are connected together by high strength plastic pins; suitable slide bars installed along longitudinal ring joints ensure the correct segment placement and adjustment. The lining waterproofing is ensured by the disposal, around each segment, of a hydro-expansive gasket.

In order to ensure long term watertightness of tunnels, a PVC membrane is installed on the inner surface of the segment ring and a second concrete ring, 25 cm thick and supporting hydrostatic head, is cast. Thus, we obtain a tunnel internal diameter of about 4.90 m.

4 MONITORING SYSTEM

In order to have a constant control, to prevent and to limit deformational phenomena during tunnel excavation, a monitoring system has been planned and provided, operating during all working phases. It includes ground surface, building and structure settlement surveying and ground depth deformation control.

The measuring of surface movements is carried out by a high precision topographical survey of the nodes of a mesh drawn along the tunnel routes, with targets installed on ground surface, on building front and on main structure along the line. In addition, a series of remote data-log level gauges connected by a fluid-filled hydraulic line are installed on every building front along the line. Deep deformations of the ground affected by excavation is controlled by bore-hole rod extensometers and extenso-inclinometer tubes for high precision 3-D measurements in bore-hole, installed from surface. Modification in water table level are measured by installation of piezometers, at regular distance along the line.

All the instruments have been installed in advance respect to the works beginning, in order to correctly evaluate the instrumental "zero" level. The acquisition data frequency during working progress has been defined in order to constantly monitor an adequate wide area centered on the tunnel face position, advancing at the same time of tunnel excavation.

5 CONCLUSIONS

Since today, 85% of the Principe-Caricamento-Grazie stretch tunnels has been excavated, with a daily excavation advance rate of about 6 m/day.

Despite the shallow overburden, superficial settlements of few millimeters have been observed, and no particular problem has been suffered by buildings and structures along the line.

Finally, at the moment, piezometer measurements exclude "barrier effect" along the seaside.