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 exhibition 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 materials.

2 GEOLOGICAL AND HYDRO-GEOLOGICAL CONDITION

The twin tunnels are situated mostly within plioene-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 overburden 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.
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 deformatonal 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 extensometer 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.