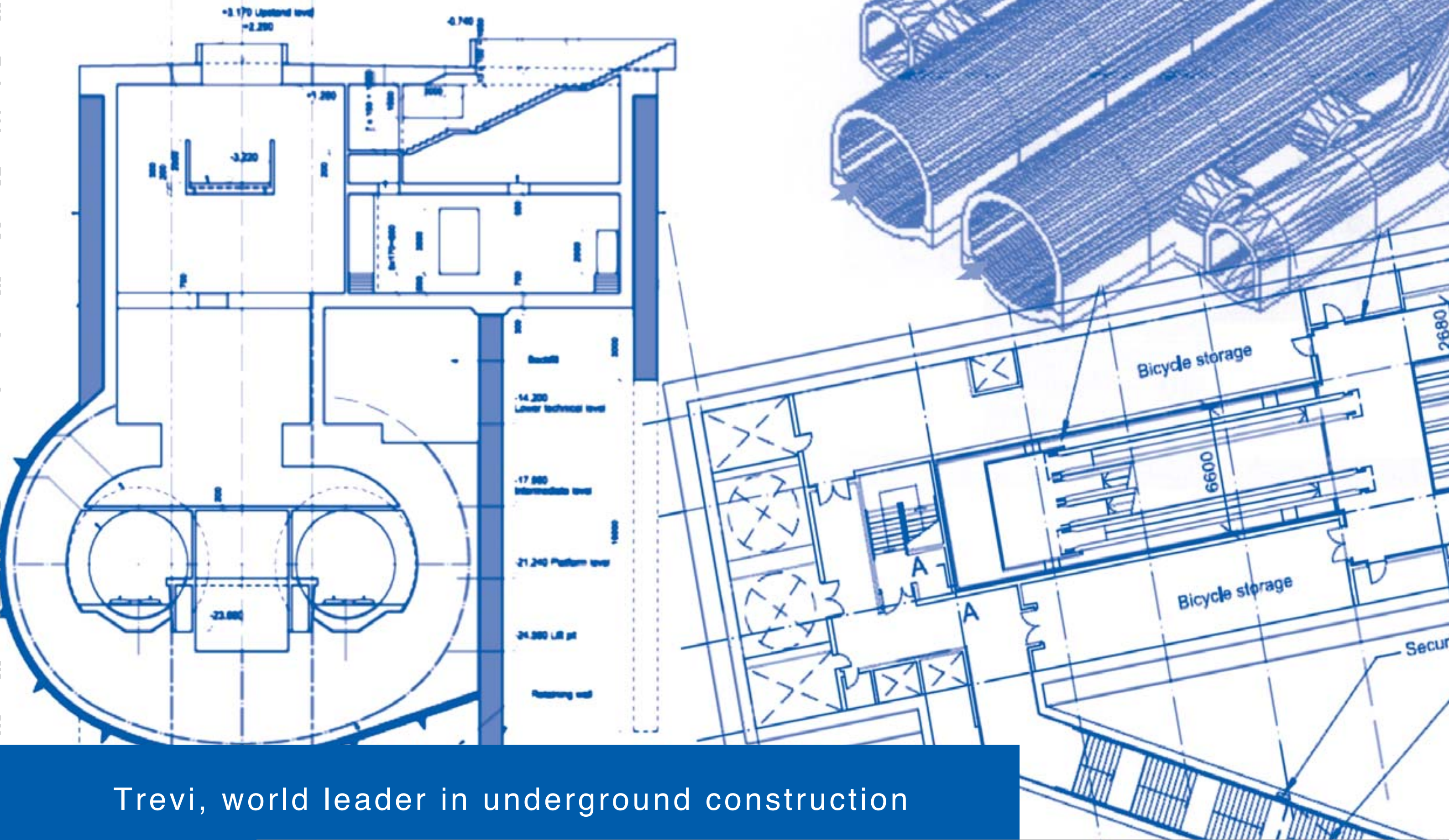


Trevi, world leader in underground construction

Metro

TREVI

The Group

Since 1957 one major Italian company has been outshining in the foundation engineering field: TREVI Group.
A group of companies *(Trevi and Soilmec engaged in the underground engineering field; Drillmec and Petreven in the Oil and Gas field)* combining constant research, innovation, wide experience and a continuous search for quality with a strong entrepreneurial tradition.

The Group has been listed on the Milan Stock Exchange since 1999.

Trevi

Trevi has managed to satisfy the multifaceted requirements of foundation industry, always showing a positive approach towards cultures different from its own. In this way, Trevi has succeeded in developing innovative global technologies - thanks to practical and first-hand analyses carried out by skilled professionals and experts - as well as modern and streamlined production systems; the teams' hard work spread out across faraway lands and was held together by shared values and by a passion that knows no borders. Nowadays, Trevi is one of the major world leaders in foundation engineering. Trevi is extremely dynamic thanks to the continuous search for new solutions to the complex problems currently being tackled by civil engineering around the world.

What are TREVI's strong points?

The ability to work in different scenarios, the willingness to challenge its own knowledge by dealing with other engineering cultures, a flexible management of human resources - by means of a continuous training -, the importance given to a positive and stimulating work environment, the choice of making its branches work autonomously and take operating decisions while never ceasing to follow the guidelines defined by the mother company.

Which targets? Safety, quality, efficiency, specialization, flexibility.

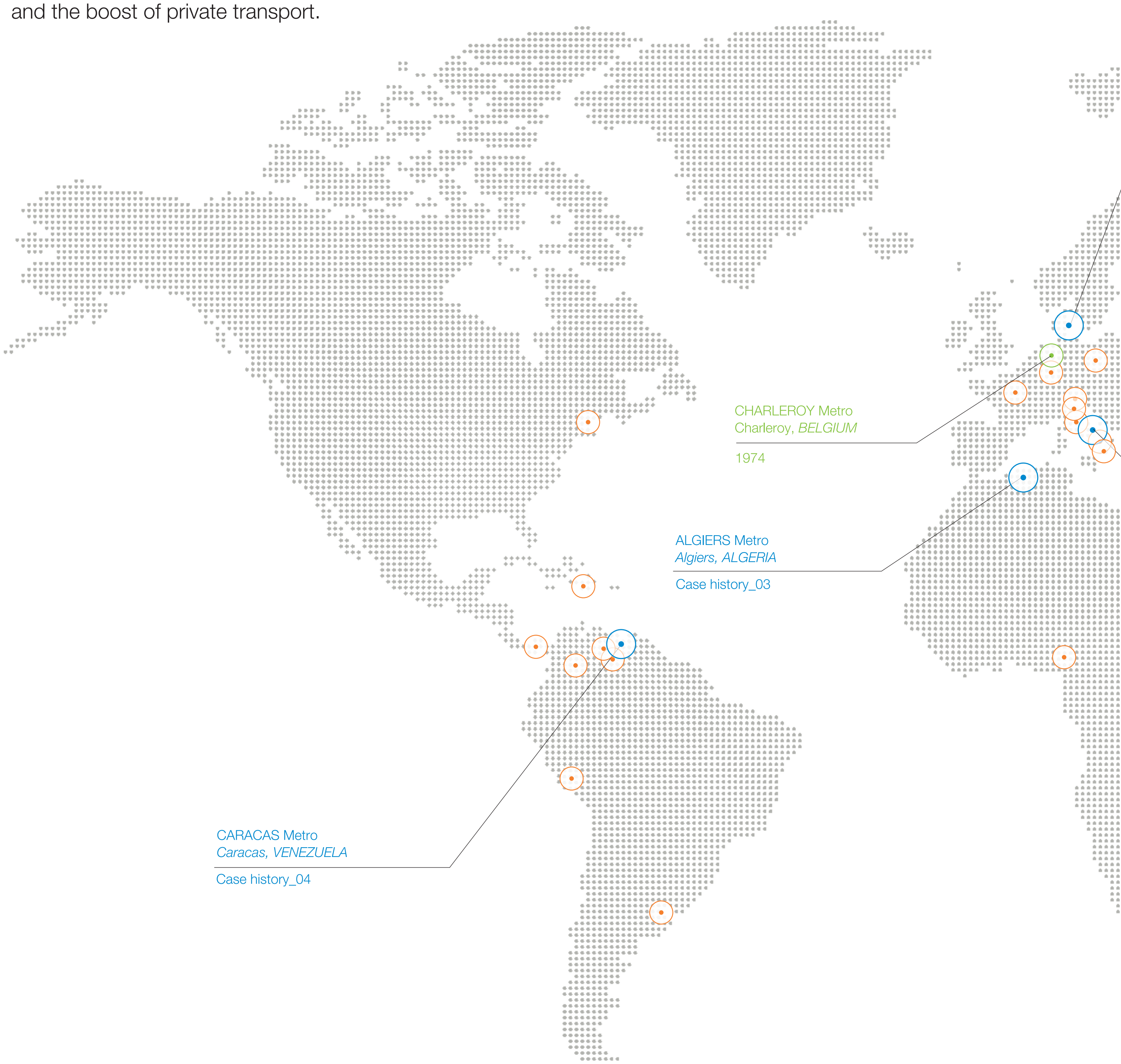
Cover: **Naples Metro - ITALY**
Picture on the right: **Algiers Metro - ALGERIA**

Trevi, the metro specialist

With the completion of almost **50 projects** in every corner of the world, Trevi consolidates its technological and technical leadership in the execution of special foundation works for metros.

The choice is almost unavoidable: either you use the underground or you have to fly! The surface, especially in big cities, doesn't allow for much manoeuvring anymore.

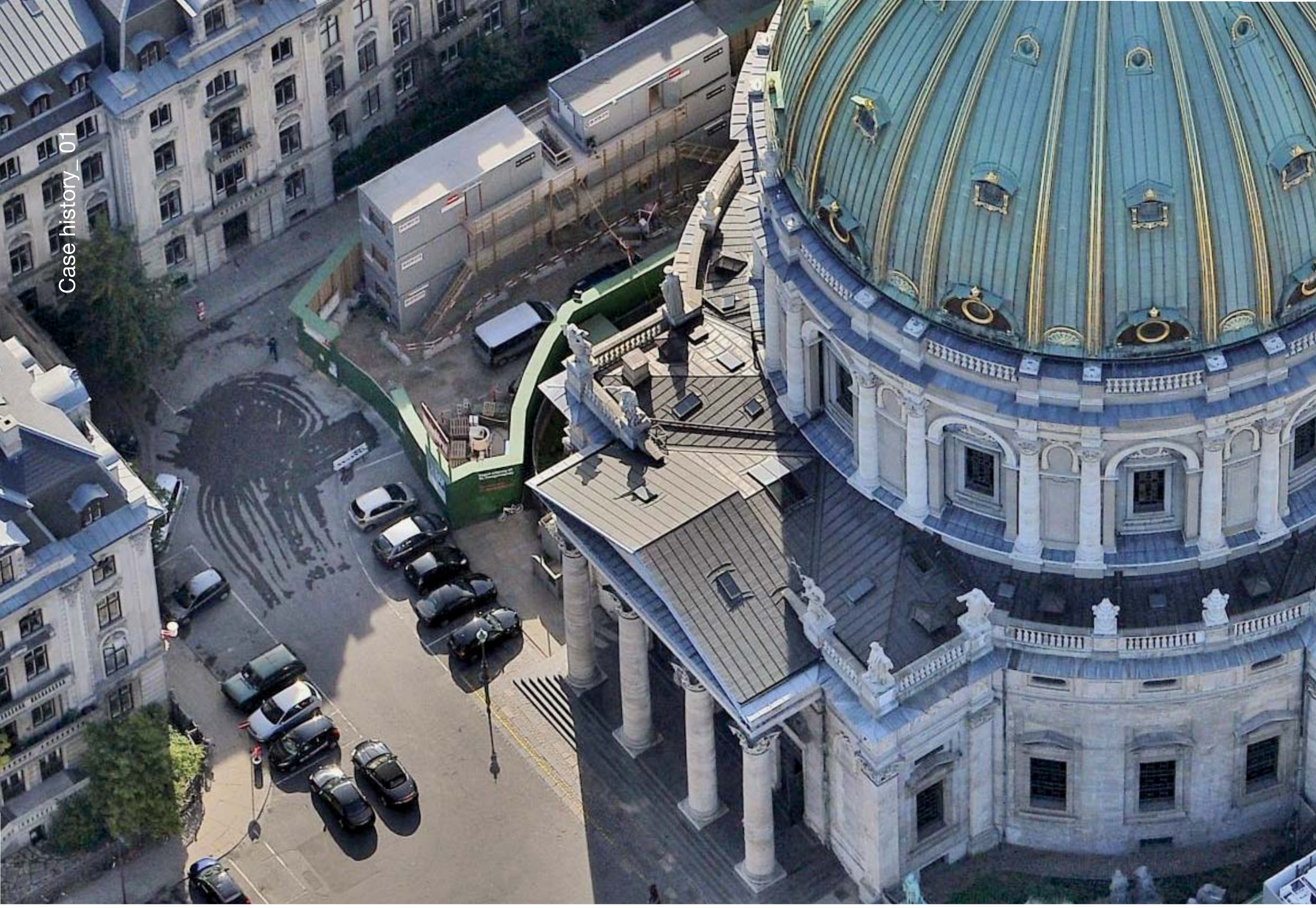
The major factors driving change in large towns and their hinterlands - also in view of reducing the environmental impact of traffic on the surface – are: the great number of travellers moving to and fro every day, the poor growth of services and facilities - also due to the policies linked to expenditure reduction -, the rapid expansion of metropolitan areas and the boost of private transport.



Therefore, the transportation of people and goods in large metropolitan areas is probably the biggest challenge that policies and companies will have to face in the coming years. That is why the issues concerning local transportation, commuting and sustainable mobility are increasingly turning into the top items in the agenda of the new Administrations of large and medium cities.

For all these reasons, metro authorities have no option but to exploit underground spaces, building metro line after metro line and excavating deeper and deeper.

Among the many metro projects carried out by Trevi, it is worth mentioning the following places where metros have been built: Algiers, Bangkok, Caracas, Milan, Leipzig, Naples, Rotterdam, Rome, Buenos Aires, Munich, Vienna, Singapore, Turin, Lagos, Nuremberg, Boston, Santo Domingo, Paris, Dubai, Cairo and the very last project in Copenhagen.



Copenhagen Circle Metro Line (Cityringen)
Copenhagen, DENMARK

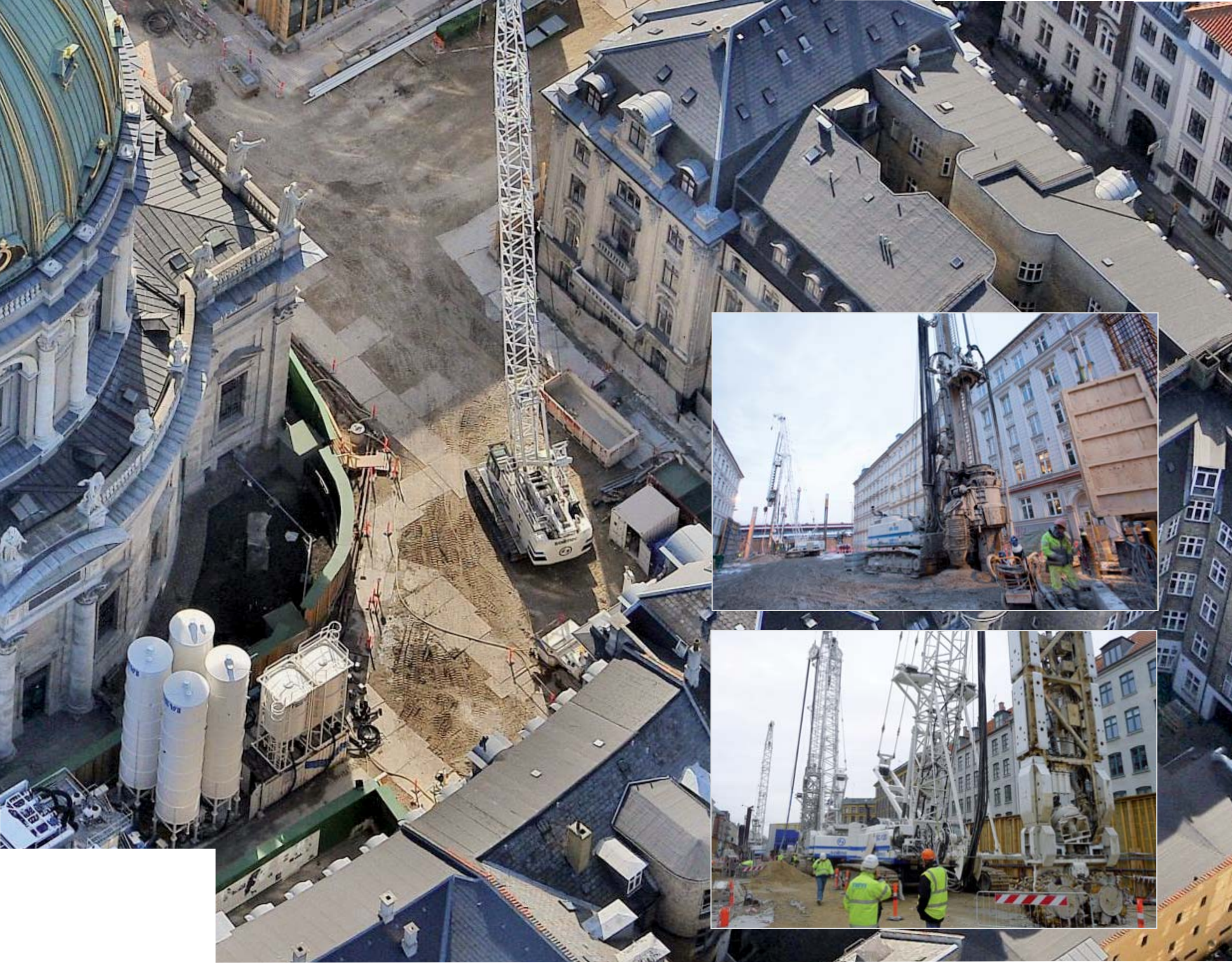
Owner:	**Metroselskabet I/S**
Main Contractor:	**Copenhagen Metro Team** *(Salini, Tecnimont, Seli)*
Completion Date:	**2013**

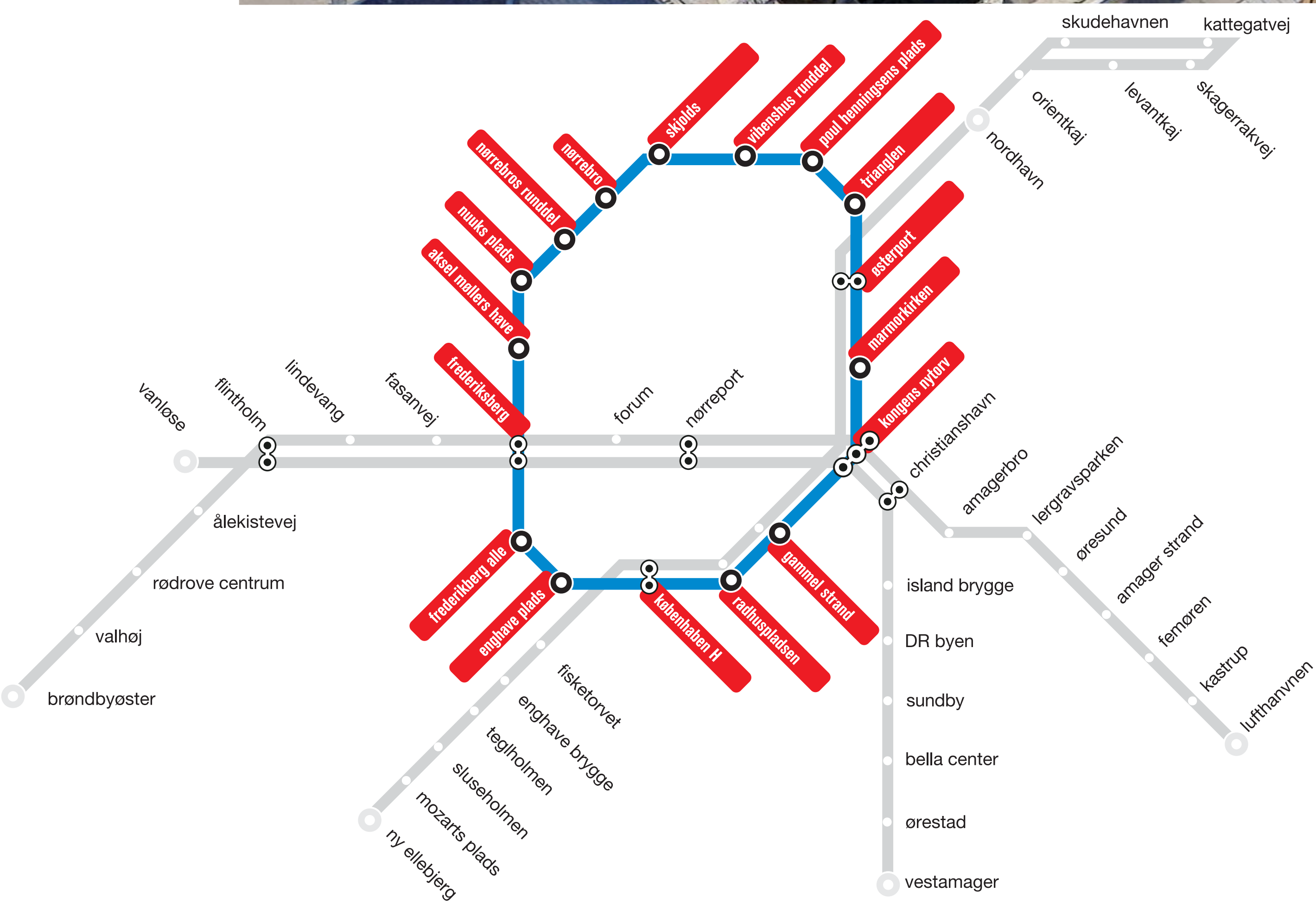
In cooperation with the Municipal Authorities of Copenhagen and Frederiksberg, the Danish Government will expand the existing Metro network of Copenhagen to create a totally new and fully automated/driverless circle line *(Cityringen)*.

The line will consist of two single- track tunnels - approximately 16 km long - seventeen underground stations with island platforms, four crossover facilities and four ventilation shafts. The line will run 24/7 with a planned operational headway of 100 seconds and it is expected to carry up to 72 million passengers a year. The design and building contract was assigned in 2011 to the Copenhagen Metro Team, an Italian Consortium including Salini Costruttori, Tecnimont and S.E.L.I.

In the same year, the Copenhagen Metro Team assigned to Trevi Foundations Denmark AS the subcontract for the execution of all foundation and soil improvement works related to the project. Trevi's activities consisted in the construction of the soil retaining structures - by means of diaphragm walls or cased secant piles *(CSP)* - of all stations and service shafts, as well as in the execution of pressure grouting and jet grouting to improve the mechanical and hydraulic characteristics of the soil in front of the stations. Besides the restricted work areas, the main difficulties were due to the peculiar nature of the soils underlying the city of Copenhagen.
Indeed, below approx. 10 m of till *(a heterogeneous glacial formation consisting of silty sand, clay and boulders)* lays a hard to very hard limestone formation which includes, randomly, highly abrasive siliceous strata of Flint. To overcome this particular condition, Trevi made use of compact and semi-compact last-generation Hydromills and of the most advanced heavy-duty piling rigs and tools.

Diaphragm walls:	**60.000 m^2**
CSP Piles:	**125.000 m**
Jet grouting:	**15.000 m**
Micropiles:	**12.000 m**

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vestamager
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teglholmen
sluseholmen
mozarts plads
ny ellebjerg

Naples Metro Line 1-6

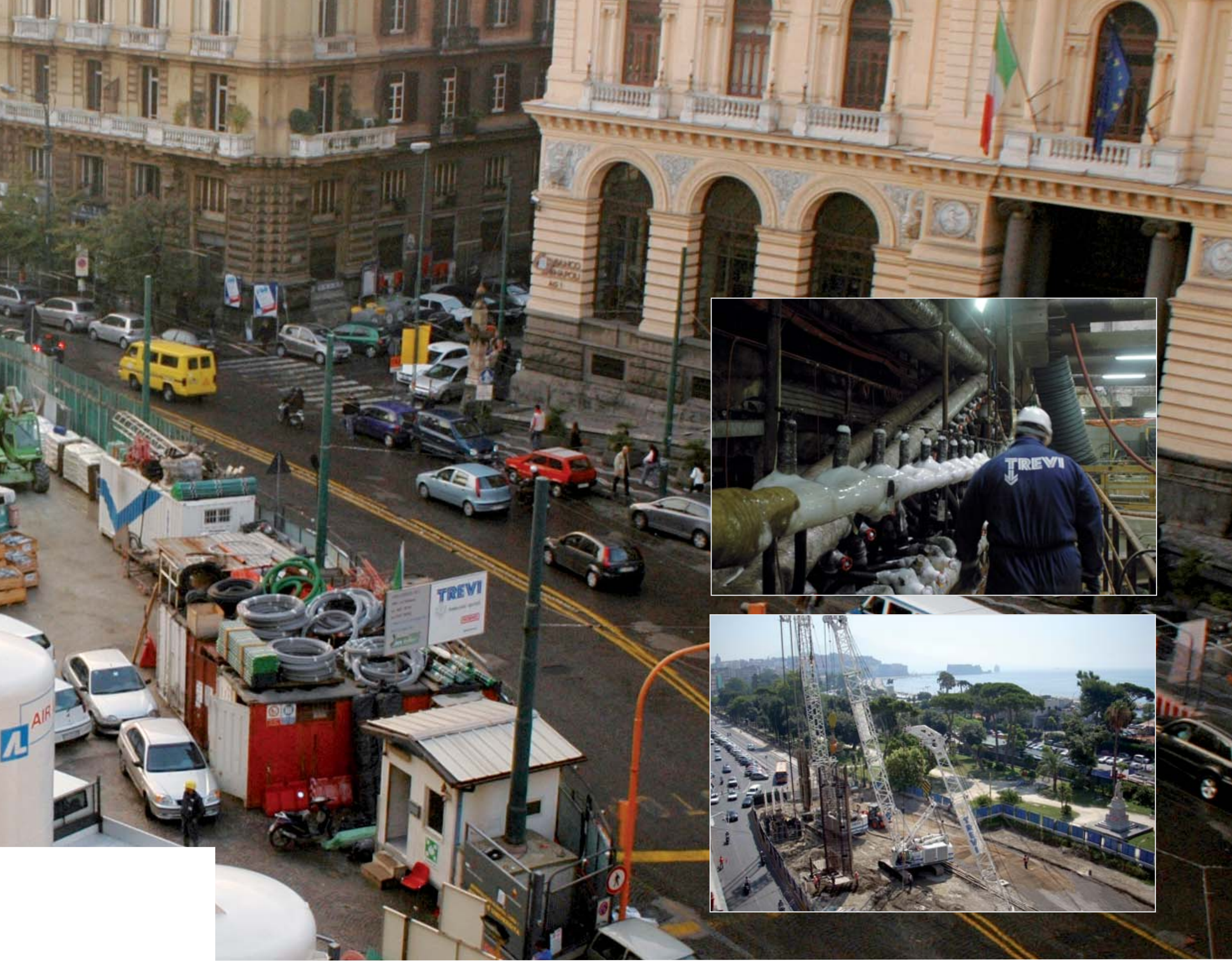
Naples, ITALY

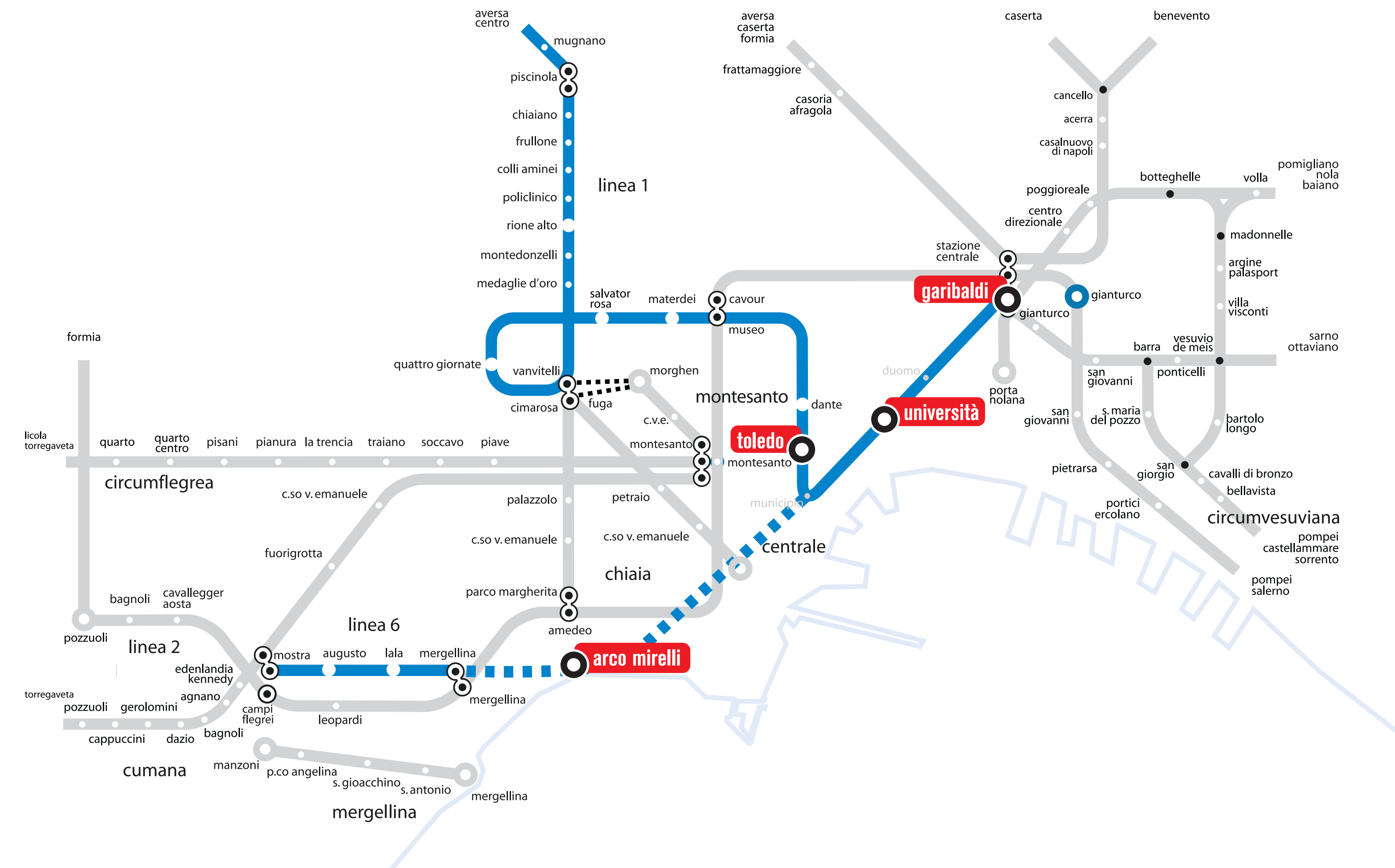
Owner:	**Metropolitana di Napoli S.p.A.**
Main Contractor:	**Toledo S.c.a r.l. (Astaldi-Moccia), Pizzarotti**
Completion Date:	**2011**

Naples Metro Line 1 was opened in 1993, but its conception dates back to the Sixties. In the last 20 years it has been largely extended and now consists of seventeen stations, for a total length of around 18 km. Line 6 is a more recent section that, once completed, will connect the district of Fuorigrotta with Municipio Station *(Line 1)* through six intermediate stations, thus covering a distance of 5,5 km.

Trevi has been involved in the construction of three stations along Line 1 *(Garibaldi, Toledo and Università)* and one station along Line 6 *(Arco Mirelli)*. The presence of sensitive historical buildings in close proximity to the work areas, together with the nature of the subsoil *(sandy formations)* and the high water table, has led to the use of innovative technological solutions to reduce the risk of hazardous situations on the surface. Indeed, Trevi employed next generation Hydromills - for the execution of the deep diaphragm walls confining the stations - and the most advanced soil improvement methods. Together with pressure grouting and jet grouting, several soil freezing techniques *(through liquid nitrogen, brine and mixed system)* have been largely used to stabilize fine soils where other technologies failed to be sufficiently effective. For the installation of long freezing pipes, Trevi has adopted a new directional drilling technology *(TDDT)* capable of ensuring very limited deviations up to a length of 55 m.

Diaphragm walls:	**31.200 m^2**
Ground freezing:	**85.000 m^3**
Directional drilling:	**75.000 m**


TREVI
AIR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materdei
cavour
museo
quattro giornate
vanvitelli
morghen
cimarosa
fuga
montesanto
dante
c.v.e.
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toledo
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municipio
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frattamaggiore
casoria afragola
caserta
benevento
cancello
acerra
casalnuovo di napoli
poggioreale
botteghelle
volla
pomigliano nola baiano
centro direzionale
madonnelle
stazione centrale
garibaldi
gianturco
gianturco
argine palasport
villa visconti
duomo
porta nolana
università
barra
vesuvio de meis
sarno ottaviano
san giovanni
ponticelli
san giovanni
s. maria del pozzo
bartolo longo
pietrarsa
san giorgio
cavalli di bronzo
bellavista
portici ercolano
circumvesuviana
pompei castellammare sorrento
pompei salerno
formia
licola torregaveta
quarto
quarto centro
pisani
pianura
la trencia
traiano
soccavo
piave
circumflegrea
c.so v. emanuele
palazzolo
petraio
fuorigrotta
c.so v. emanuele
c.so v. emanuele
centrale
chiaia
parco margherita
amedeo
bagnoli
cavallegger aosta
pozzuoli
linea 2
linea 6
mostra
augusto
lala
mergellina
arco mirelli
edenlandia kennedy
torregaveta
pozzuoli
gerolomini
agnano
campi flegrei
leopardi
mergellina
cappuccini
dazio
bagnoli
cumana
manzoni
p.co angelina
s. gioacchino
s. antonio
mergellina
mergellina

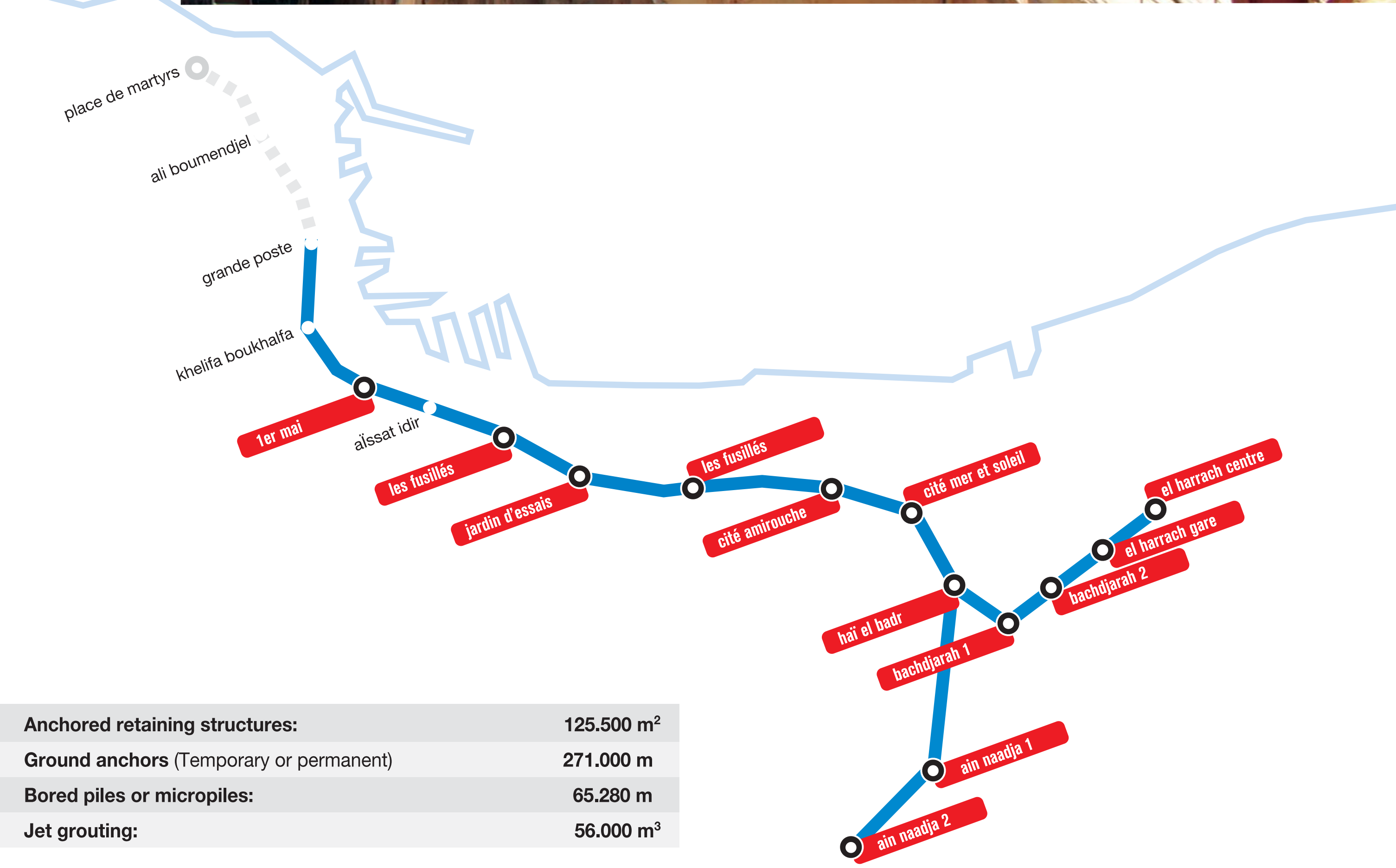
Algiers Metro Line 1
Algiers, ALGERIA

Owner:	**Entreprise Métro d'Alger (EMA)**
Main Contractor:	Groupement **GAAMA** Groupement **GDTC** Groupement **GDC**
Completion Date:	**2006** Section Hamma -Hai El Badr **2012** Extension B - El Badr-El Arrach **2014** Extension C - Hai El Badr-Ain Naadja

The implementation of a modern underground metro network in Algiers, one of the most populated towns in North Africa, has always been considered a top priority for the Algerian Government.

Envisaged since the Seventies, the project was officially unveiled in 1982 and the first technical studies were accomplished in 1985. The overall master-plan includes the construction of 3 lines and 54 stations, for a total running length of about 64 km. Nowadays, a first 9,5 km section, including 10 stations, is fully operational and 2 extensions, including 6 additional stations, are under completion and scheduled to open in 2015. Trevi has played a key role in the development of this challenging scheme. Indeed, since 2004, Trevi has been involved in the construction of all foundations and soil consolidation activities associated to the project. Due to the high heterogeneity of the soils underlying the city of Algiers, different technical solutions and equipment have been adopted for the construction of the retaining walls in correspondence of the stations and service shafts.

Continuous diaphragm walls and cased secant pile walls *(CSP)* have been implemented in the areas where the subsoil was characterized by fine-grained formations associated to a high water table, while contiguous bored pile walls were generally executed in cohesive soils. Next generation equipment and tools have been used to this purpose.
The diaphragm walls have been performed by means of compact and semi-compact hydromills, thanks to their capability to cross and penetrate into dense and hard formations without producing noise and vibrations. Similarly, advanced rotary or CSP piling rigs have been used to execute the piles in the other locations. Temporary or permanent strand anchors have been generally adopted for anchoring the retaining structures. All ground anchors were performed step by step by following the excavation of the soil within the retaining structure and were subsequently assembled in dedicated sheltered areas established at site. The double-fluid jet grouting technique has been widely adopted to improve the characteristics of the soil around the profile of the mined tunnels to be excavated or to create “impervious” plugs at the bottom of some stations in order to counteract the hydrostatic pressure.



Anchored retaining structures:	125.500 m^2
Ground anchors (Temporary or permanent)	271.000 m
Bored piles or micropiles:	65.280 m
Jet grouting:	56.000 m^3

Caracas Metro Line 3
Caracas, VENEZUELA

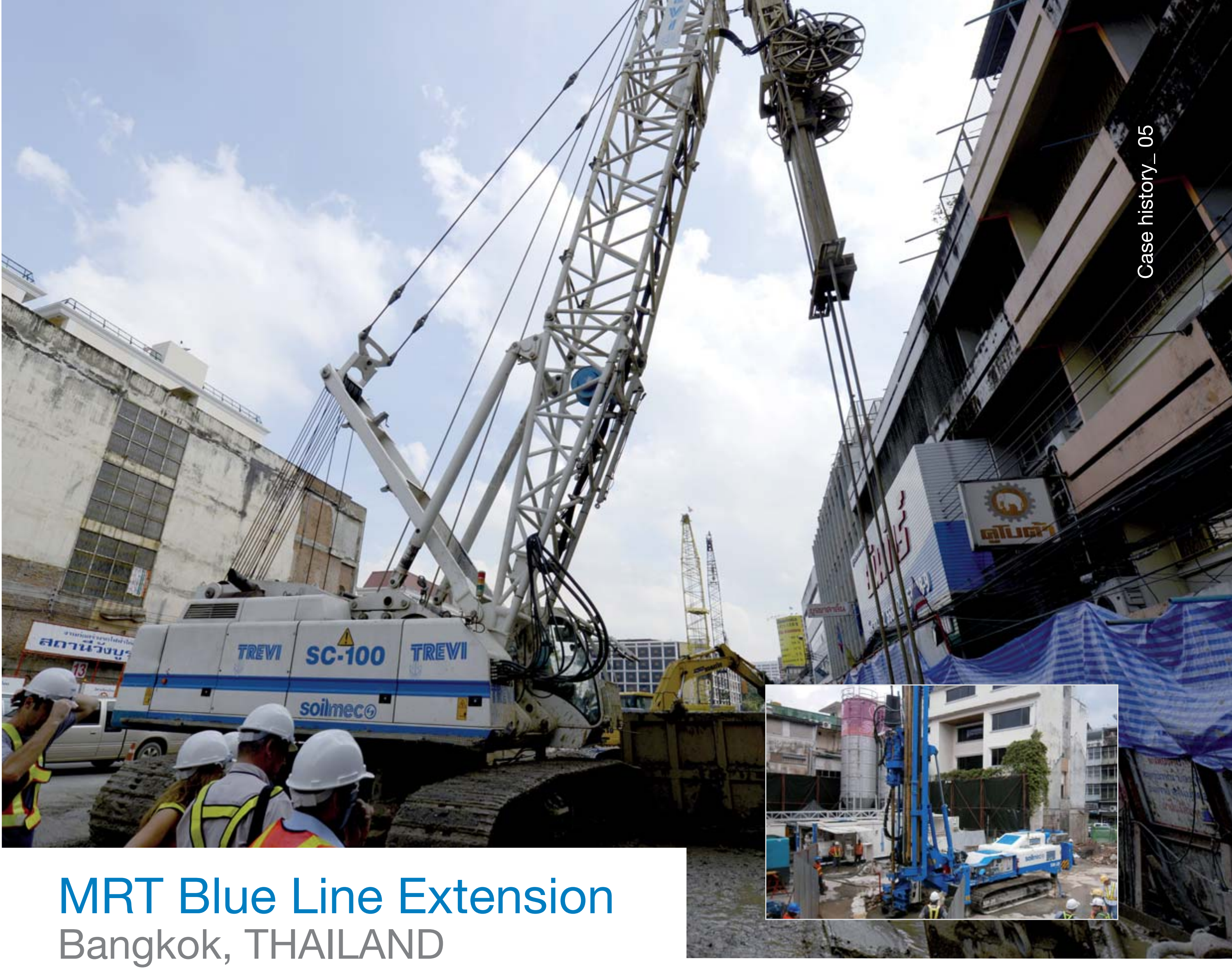
Owner:	**Metro de Caracas**
Contractor:	**Consorcio Ghella - Sogene - Cogefar Impresit**
Completion Date:	**1992**

The construction of Caracas Metro Line 3 started in 1991. Including five new stations and one manoeuvring structure, the line runs underground for 10 km - from the existing Plaza Venezuela 2 Station to La Rinconada Station - almost perpendicularly to Line 1.

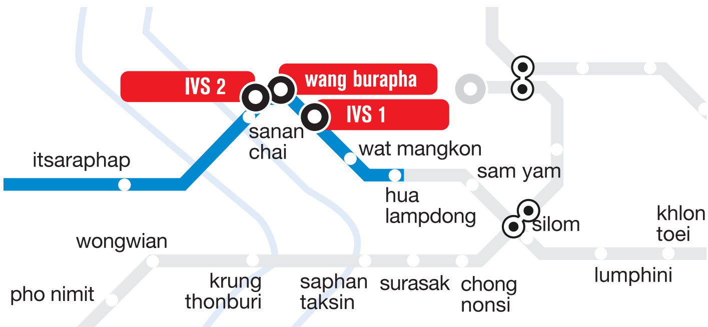
Trevi's involvement in the project consisted in the execution of the soil retaining walls for three underground structures and of the supporting anchors for all the six structures. The soil retaining structures consisted of 600 mm, 800 mm and 1000 mm thick diaphragm walls driven down to 50 m. According to the excavation depth, the diaphragm walls were supported either by tubular struts or by strand anchors.

The works at Plaza Venezuela were particularly demanding; here, the new station had to be constructed below the existing Plaza Venezuela 2 Station. In this location, anchored diaphragm walls down to a depth of 35 m were performed, operating within restricted work areas.

Diaphragm walls:	**40.500 m^2**
Ground anchors (Temporary)**:**	**150.000 m**



MRT Blue Line Extension
Bangkok, THAILAND



Owner:	**Mass Rapid Transit Authority (MRTA) of Thailand**
Main Contractor:	**Italian-Thai Development PLC**
Completion Date:	**2014**

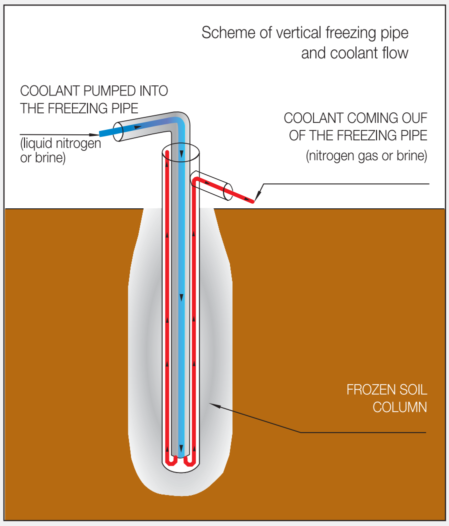
The Blue Line, the first underground metro line in Bangkok, was completed and opened in July 2004. Consisting of 18 underground stations, it runs for 27 km from Hua Lamphong Station to Bang Sue Station, crossing the main business district of the city. In 2010, to meet the demand of a growing population, the Mass Rapid Transit Authority *(MRTA)* of Thailand awarded the construction of a 27 km southward extension of the Blue Line.
The project includes a 5.5 km underground section with 4 stations and 3 intervention shafts, while the remaining 21.5 km are elevated and include 15 additional stations. Passing underneath the Chao Phraya, the main river crossing the city, the underground section will serve one of the most populated and traffic-congested areas of Bangkok, the Old China Town District *(Yao Warat)*, and is scheduled to open in 2016. The contribution of Trevi to this challenging project consisted in the construction of the soil retaining structures for one underground station *(Wang Burapha)* and two intervention shafts *(IVS1 and IVS2)* Trevi also performed soil improvement works in six different locations.
Due to the peculiar nature of Bangkok subsoil - characterized by an alternation of recent alluvial deposits of clay and sand - to the high water table and to the presence of sensitive buildings near the structures to be erected, the Designer's technical solution for the construction of both stations and shafts envisaged the execution of 70 m deep and 1.2 m thick continuous diaphragm walls associated with a “top-down” building sequence. To ensure a perfect water-tightness of the joints between the diaphragm wall panels, a specific PVC water-stop was inserted into the steel stop-ends before the primary panels were cast. Single-fluid and double-fluid jet grouting technology has been widely applied to improve the mechanical and hydraulic characteristics of loose/soft soils, to allow the mined excavation of short adits or to ensure a safe exit/entrance of the TBM shield from/into the stations *(break-in/break-out)*.

Diaphragm walls:	**43.620 m^2**
Jet grouting:	**8.300 m^3**

Ground freezing

The AGF process involves freezing water within soil volumes, at a preset temperature, based on a known pattern, by extracting heat from the ground through special heat exchangers named freezing pipes.
Soil cooling is obtained by circulating a low temperature liquid within the soil volume to consolidate: heat is extracted and dissipated.

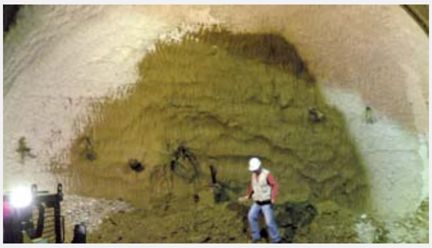
Freezing alters the hydraulic properties of soil or rocks (making them watertight), as well as the mechanical features. The compressive strength of frozen soil varies according to soil or rock type and increases as temperature decreases. The values generally applied are between -5 and -20°C; the corresponding strength values range between 3 and 20 MPa. The correct measurement of mechanic, hydraulic and thermal properties of soil is crucial to the reliable calculation of freezing time, refrigeration power and capacity needed to achieve the design values.

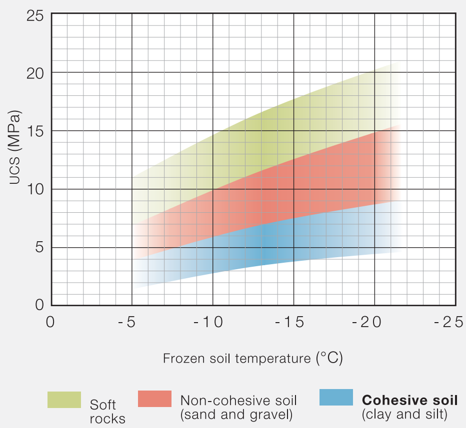


AGF involves the following stages:

Freezing stage: heat is extracted from the ground and a frozen ground wall is created with thickness and temperature set forth in the project.

Maintenance stage: the flow of heat extracted is appropriately regulated to prevent further development of the frozen volume and avoid the deterioration of the features achieved in the previous stage *(thawing).*





Depending on the coolant used, two methods can be adopted:

- liquid nitrogen freezing, also named 'open circuit' or 'direct' method: the coolant (*compressed gas in a liquid state – temperature -196°C)* circulates in an open circuit and after passing through the freezing pipes is released to the atmosphere in the gaseous state;
- brine freezing, also named 'closed circuit' or 'indirect' method: the coolant *(calcium chloride brine with freezing point between -40 °C and -50 °C)* is pumped through the freezing pipes at a temperature of - 30/-35°C: as heat is extracted from the ground the brine gets warmer and returns to the refrigeration system to be re-cooled and re-circulated into the circuit.

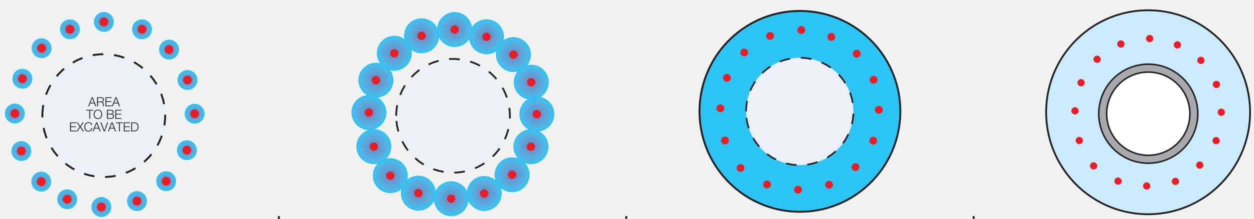
Choosing either one of the two methods mainly depends on economic factors and jobsite logistics, as well as the time needed to freeze the soil volume.
The average freezing power *(calculated in terms of electric power or amount of nitrogen)* needed to freeze one cubic metre of soil with 30% water content can be estimated as follows:

Indirect ground freezing ***(brine)***
50 - 150 kWh/m^3

Direct ground freezing ***(liquid nitrogen)***
1.000 ÷ 2.000 l/m^3

During maintenance stages, cooling powers and nitrogen volumes are generally reduced by 40-60%. The refrigeration power ranges above stated, do not take into account local factors, related to the peculiarities of each project, such as abnormal soil or water temperature, high salinity, length and type of insulation of the coolant distribution system and the inactivated lengths of freezing pipes to calculate the heat losses.

FREEZING STAGES



Freezing stage
the frozen wall develops

Freezing stage
gaps between frozen columns are closed

Freezing stage is completed
Design thickness and temperature are reached

Maintenance stage

Technologies special application
for metro construction

SOIL INVESTIGATION

The purpose of geognostic surveys is to deliver the necessary data and information for the classification of soil and rock, in order to provide an adequate assessment of the geotechnical parameters to be used for design.

SHEET PILING

Sheet piling is a widespread technology in many engineering fields. This is an advantageous solution for supporting excavations, protection of side walls and in marine works, just to mention a few of the many possible applications.

BORED PILES

The bored piles technology represents a technology that differs from the similar one used on the ground. As a matter of fact, execution difficulties linked to a hard working environment - due to the presence of tides, bad weather, currents and so on -, require an organization capable of quickly facing and solving contingencies.

DIAPHRAGM WALLS

Diaphragm walls are walls built in the underground starting from the surface. Their use has evolved since last century's early years old practice of adding bentonite to drilling fluids in order to stabilize uncased drill holes. They are performed through trench digging, and filling it with bentonite mud, then placing a reinforcement (steel cages, soldier piles, etc.). Finally the slurry is displaced by means of the subsequent concrete placement casting by tremie method.

HYDROMILL

Diaphragm walls are common practice in civil engineering as part of or as aids to the building of civil and hydraulic structures. Hence, they can be either temporary or permanent.
In the realm of structural diaphragm walls a distinction exists between retaining structures (earth and hydraulic) and foundations. Those walls, whose purpose is hydraulic, can be sub-classified into impervious (cut off) and draining.

TIE RODS AND ANCHORS

These are structural elements undergoing traction and suitable for conveying loads to soil depths. They consist of an active part, the bond length, and a passive part, that transfers the stresses from the anchoring head placed on the anchor wall to the soil. They can be grouted either by low pressure or by high pressure, while, as far as their duration is concerned, they can be classified as temporary and/or permanent.

JET GROUTING

By means of the TREVIJET system it is possible to obtain columns with the following diameters:
- *0.35 - 1.00 m by means of TREVIJET T1*
- *0.60 - 2.50 m by means of TREVIJET T1/S*
- *1.40 - 3.50 m by means of TREVIJET T2*

Said dimensions and the mechanical features of the treated soil highly depend on the combination of several elements, such as the nature of the soil, the jetting parameters and the composition of the grouting mixture.

TURBOJET

With the TREVIMIX-TURBOJET technique it is possible to obtains columns of consolidated soil, with geometry defined by the tool's dimensions. The in-situ mechanical mixing of the soil with the supply of a water-cement mixture injected at medium-high pressure produces high quality product.
The results achieved with the TURBOJET treatment strictly depend on the nature and composition of the soil where the operation is being carried out

MICROPILES

Micropiles make possible to solve some problems concerning the execution of foundations, thanks to the possibility of using equipment with reduced sizes and encumbrance, and to the minimal disturbance caused to the soils and pre-existing structures.

TDDT
(Trevi Directional Drilling Technology)

TDDT (Trevi Directional Drilling Technology) is a technology that allows the execution of small diameter holes (50-200 mm) and of considerable length (generally longer than 40 meters, and up to a few hundreds meters). The method has been developed by TREVI by implementing tools and methods used in the oil and the HDD industries.
By increasing the accuracy of drilling, it allows to stretch the boundaries of conventional geotechnical works. In fact, TDDT allows increasingly dramatic field applications with respect to the conventional methods. This method has been successfully used to drill accurate pilot holes for the execution of cut-off walls by secant piles for the rehabilitation of dams, or for artificial ground freezing and compensation grouting.

Note: for any further information about technologies please refer to the technology section inside ***www.trevispa.com***

www.trevispa.com

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