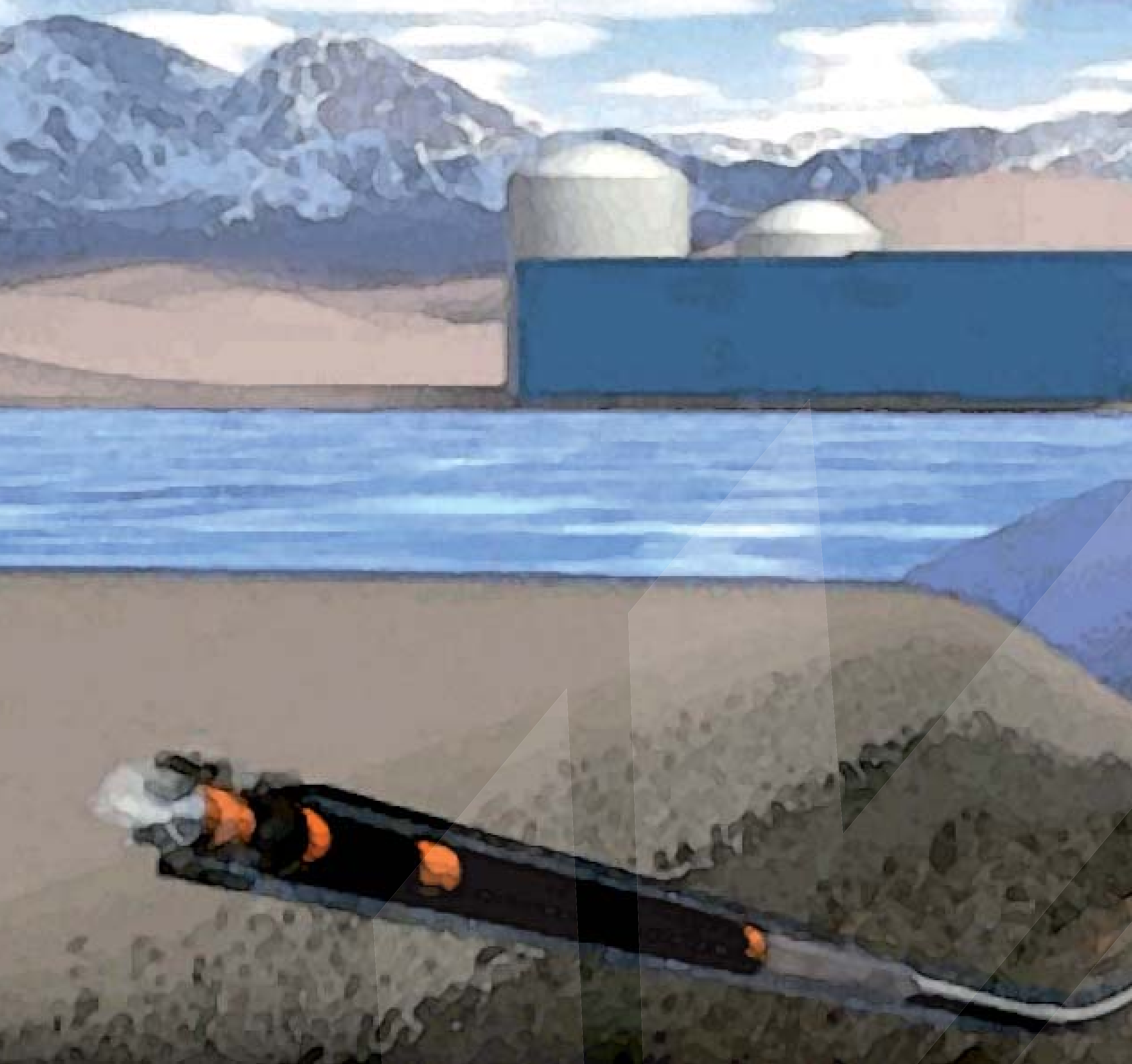


TECHNOLOGY

TDDT

Trevi Directional Drilling Technology

TREVI

Technology

The **TDDT system** stems from the HDD *(Horizontal Directional Drilling)* technologies used to lay utilities (usually cables and pipes) underneath surface obstacles *(water streams, roads, railways, structures, buildings, etc.)*.
In turn, much of the technological equipment adopted in this sector comes from the oil industry.

Trevi applied the said technologies to the geotechnical field, thus benefiting from production potentials and positioning accuracy. The system developed is named **TDDT** *(Trevi Directional Drilling Technology)* and includes a number of devices that enable to drill small-diameter boreholes *(50-200 mm)* of considerable length *(generally from 25-30m to a few hundred metres)*.

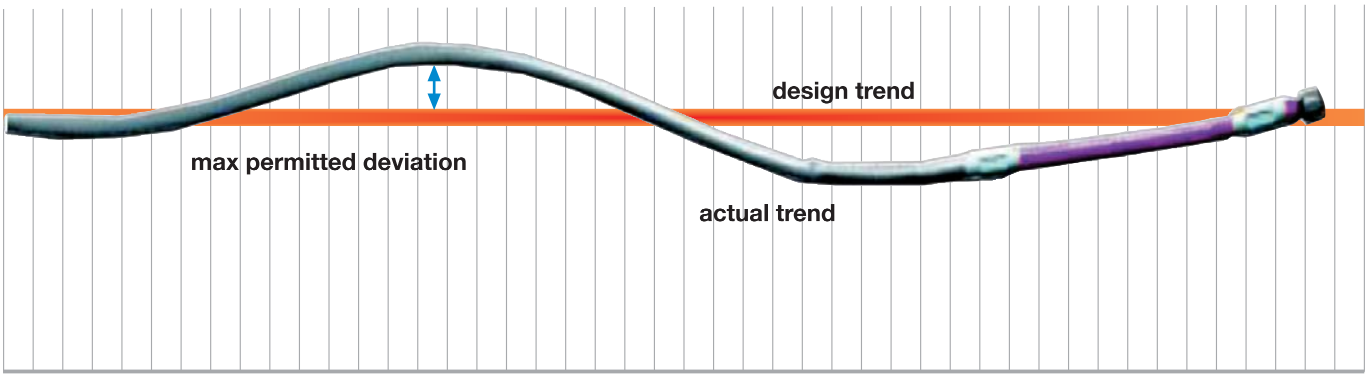
By using TDDT, boreholes can be drilled both above and under the water table, even combined with the use of a BOP *(blow-out preventer)*, and drilling can be carried out in any direction *(including vertical and horizontal directions)*.

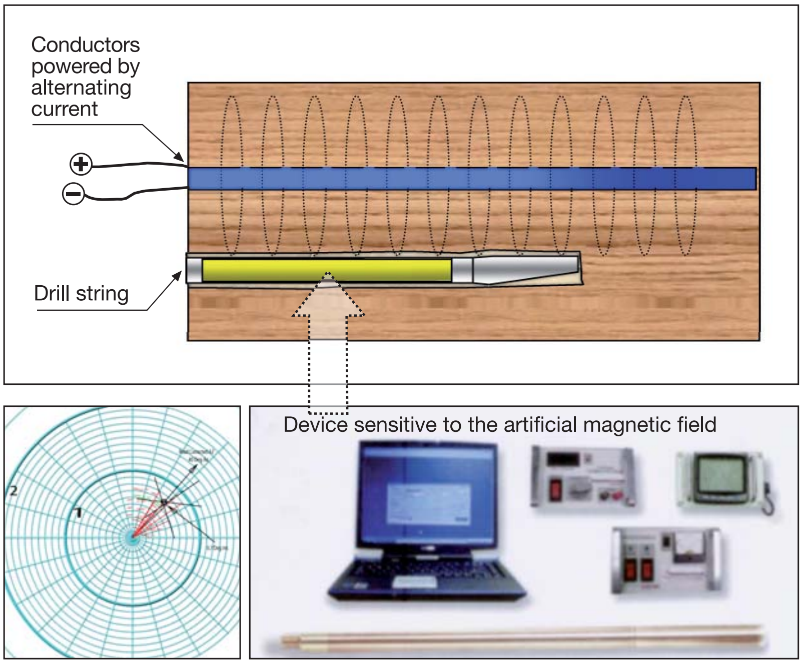
The TDDT has been successfully used in some important Trevi jobsites for soil consolidation and waterproofing.

Drilling can be either rectilinear or curvilinear. In the latter case, the radius of curvature depending on the diameter and thicknesses of the rods and casings used.
Drilling can be carried out in any soil type *(cohesive or non-cohesive)*, including rocks. For this type of drilling, standard equipment is generally used *(drilling rigs, pumps, rods)*, whereas more complex projects need specific equipment.

Directional drilling is accomplished in three main stages:

- **design of the bore path**
- **real time measurement of drilling data**
- **comparison of real data with theoretical data and, if needed, correction of drilling.**





Guidance system / Application	WALK OVER	MAGNETIC GUIDANCE	COMPASS and INCLINOMETER	OPTICAL GUIDANCE
Horizontal drilling >40 m	●	●		
Vertical drilling		●	●	
Horizontal drilling <40 m	●	●		●

TREVI adopted a number of guidance systems to meet various project needs.

The most commonly used systems are the following:

Walk-over locating system

in which the drill bit position is detected from the surface.
It is used for max depths of 10-15m.
Accuracy is generally 5% of depth.

Magnetic guidance system

(with respect to the Earth's magnetic field or to an artificial magnetic field), in which the drill bit position is calculated by using a sensor assembled on the drill string.
It is used when high accuracy is a must. Generally speaking, accuracy ranges roughly from 50 to 200 mm, depending on the distance between the bit and the reference electric field.

Compass + Inclinometer

suitable for vertical drilling. Accuracy is 0.1% of depth.

Optical guidance system

suitable for rectilinear boreholes; the rectilinearity of the borehole is detected by an optical device.
It ensures few errors *(10-30 mm)*.
As the system involves the optical matching of a target within the drill string, it is not suitable for curvilinear boreholes or however boreholes longer than 40 m.

Either one of the abovementioned systems is adopted depending on logistic conditions.

It should be noted that productivity *(and thus costs)* are proportionate to the level of accuracy demanded.

Positioning accuracy depends not only on devices, but also on the tools' ability to correct it. As a result, accuracy can vary according to soil conditions too. Generally speaking, positioning with a 150mm tolerance is guaranteed, which is appropriate for geotechnical purposes.

Either one of the abovementioned systems is adopted depending on the environmental conditions of the intervention, on the shape of the borehole and level of accuracy demanded.

Tools

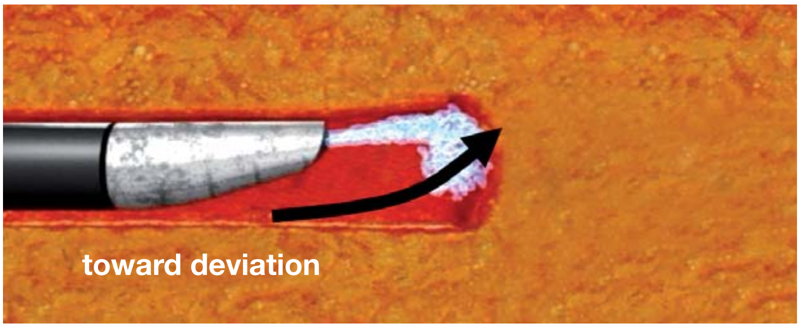
The drilling control technique is essentially based on two types of drilling tools:

- **asymmetric or bevelled drill bits**
- **fixed-angle bent subs**

Both types of tools are suitable for non-cohesive soft soils or stony soils and rocks.
When driving the asymmetric drill bit into the soil with no rotation, its flat side is pushed away by the soil.

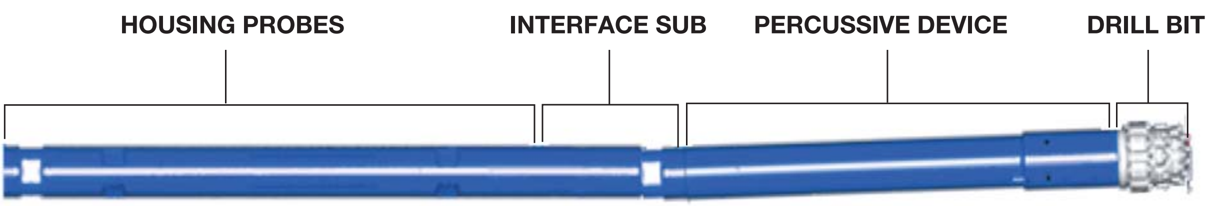
In presence of very hardsoil, the bit can be fitted with rock teeth, whereas in rock a **down-the-hole** hammer can be used with a suitable drill bit.
Alternatively, a bent sub can be installed upstream of the bit in order to force this to deviate when pushed without rotating the drill string.

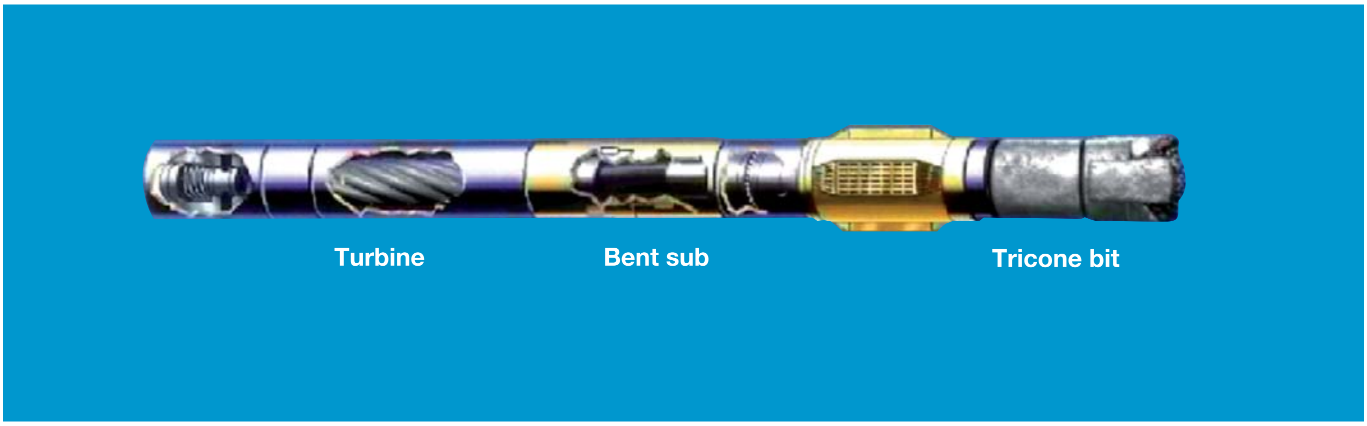
In case of drilling into rock, a down-the-hole hammer can be used in combination with the bent-sub. However, if the use of the hammer is prohibited, a turbine (or mud motor) can be used instead. Activated by the drilling mud, the turbine makes the bit rotate even if the string and the bent sub do not rotate. The activation of such a tool requires pumps delivering high flow rates *(400 -700 l/min)*, this resulting in high running costs.



Drill bit for hard soil, soft rock

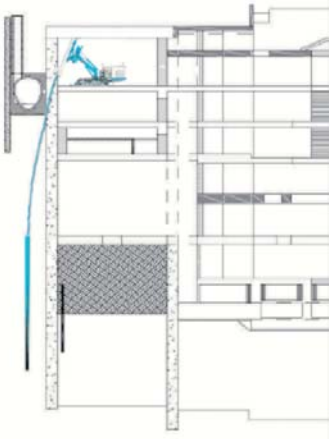
Slanted drill bit for down-the-hole hammer



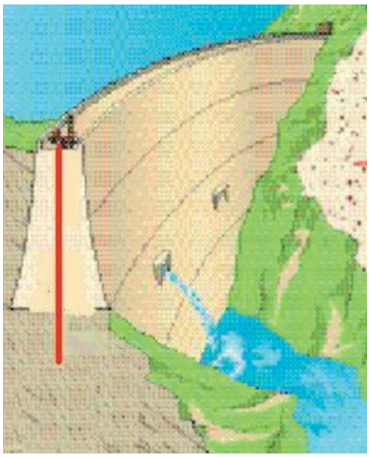


Applications

DIAPHRAGM WALL REPAIR



DAM REPAIR



TREVI implemented the TDDT in the following sectors:

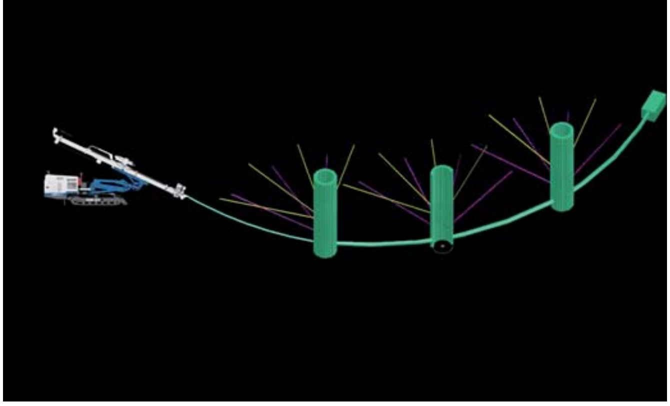
ENVIRONMENTAL RECOVERY
DAM REPAIR
TUNNELLING
DIAPHRAGM WALL REPAIR
CONNECTION BETWEEN DRAINAGE WELLS
SEISMIC RISK MITIGATION

Namely, drilling was carried out for the following purposes:

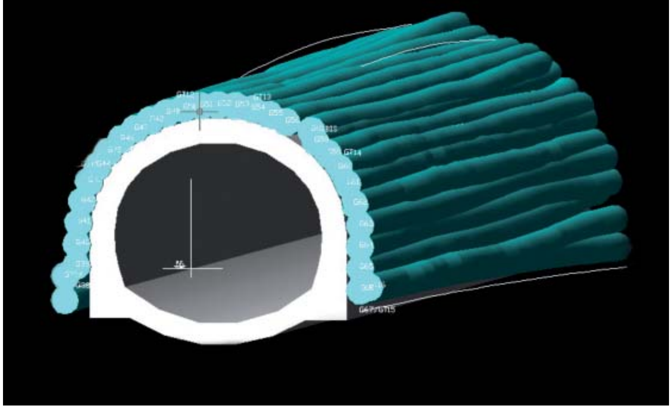
- waterproofing grouting, compensation grouting and soil anti-liquefaction consolidation
- drain pipe laying
- vertical boreholes to guide secant piles
- weight reduction vertical boreholes
- tunnel forepoling
- laying of freezing pipes
- bottom connection of drainage wells
- vertical boreholes to repair diaphragm walls
- directional investigations.

A preliminary feasibility study is required for the aforesaid interventions. Trevi Technical Service is available to carry out checks and detailed assessments.

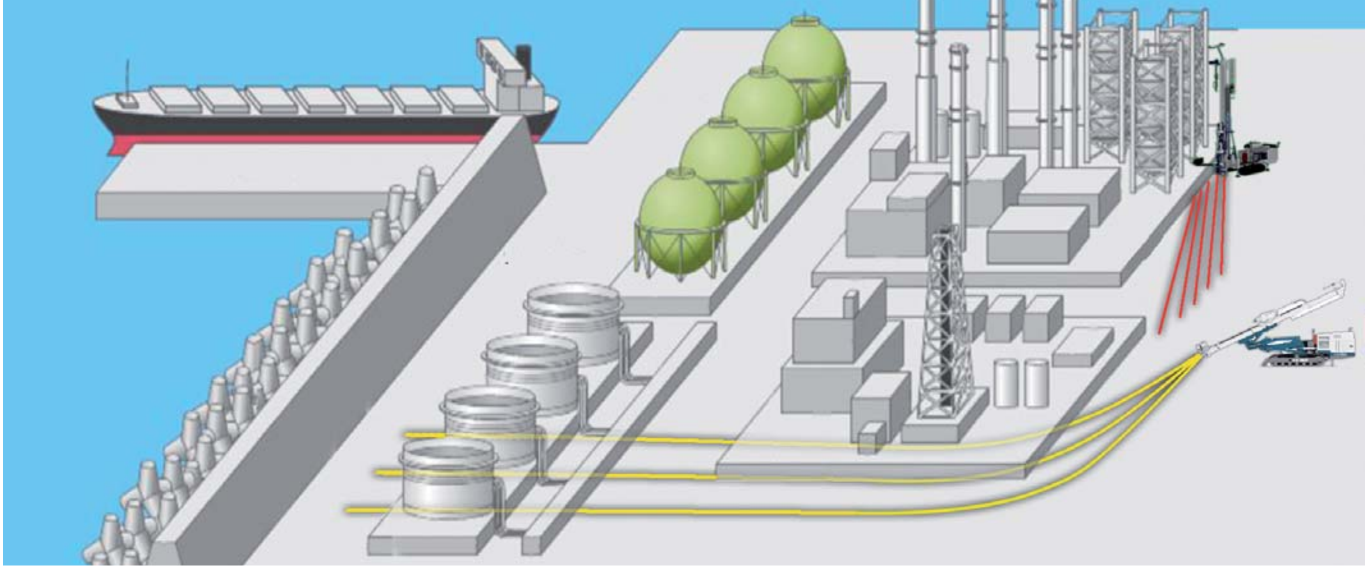
CONNECTION OF DRAINAGE WELLS



TUNNELLING



ENVIRONMENTAL RECOVERY



Advantages

The TDDT allows to drill by following preset paths to accurately reach the desired area. Common applications include compensation grouting and grouting under areas to be reclaimed, consolidated or waterproofed:

- **cost cutting as no shaft is needed;**
- **increased flexibility, as drilling can be started from a number of areas depending on available surface;**
- **maximization of the position of the port-fitted portions of TAMs;**
- **possibility to access areas underneath structures or obstacles that cannot be removed.**

They are generally used to carry out consolidation aimed at excavating tunnels, combined with the laying of freezing pipes, tubular reinforcements, grouting pipes.

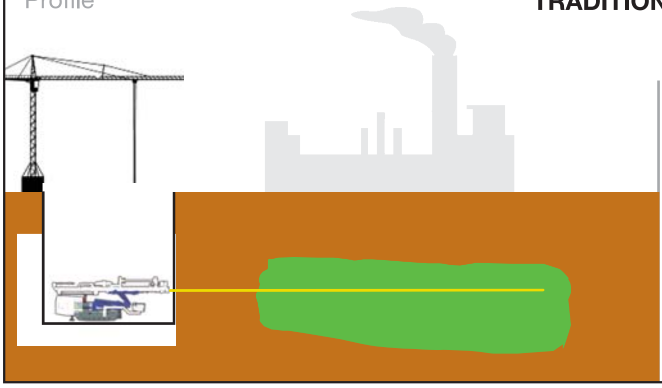
- **Tunnels can be excavated in long stretches, reducing excavation and consolidation stages;**
- **positionings are considerably reduced, thus decreasing costs;**
- **field overlapping is reduced, thus decreasing over-augering volumes;**
- **the section is consistent throughout the drilled length, making the project easier;**
- **consolidation and drilling stages are separated, resulting in time optimization;**
- **possible application of a number of technologies such as freezing, that would otherwise be difficult to use in a truncated cone-shaped borehole.**

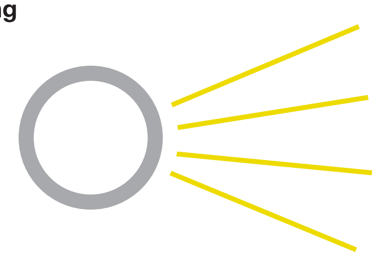
REHABILITATION OF CONTAMINATED SOIL AND WATERPROOFING

Profile

TRADITIONAL drilling

Plan



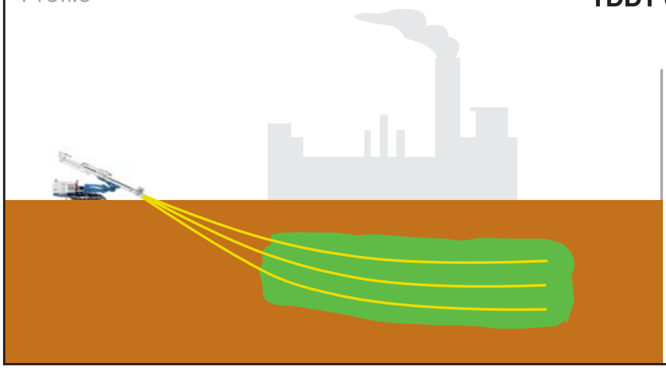


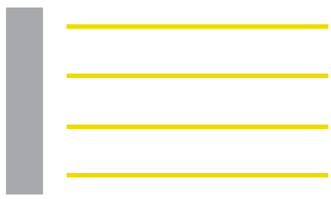
Radial arrangement:
boreholes diverge and make the distance between them variable.

Profile

TDDT drilling

Plan

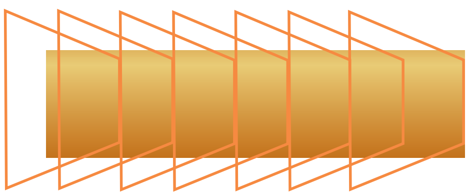




Boreholes can be drilled in parallel rows to ensure maximum intervention consistency.

TUNNELLING

TRADITIONAL drilling

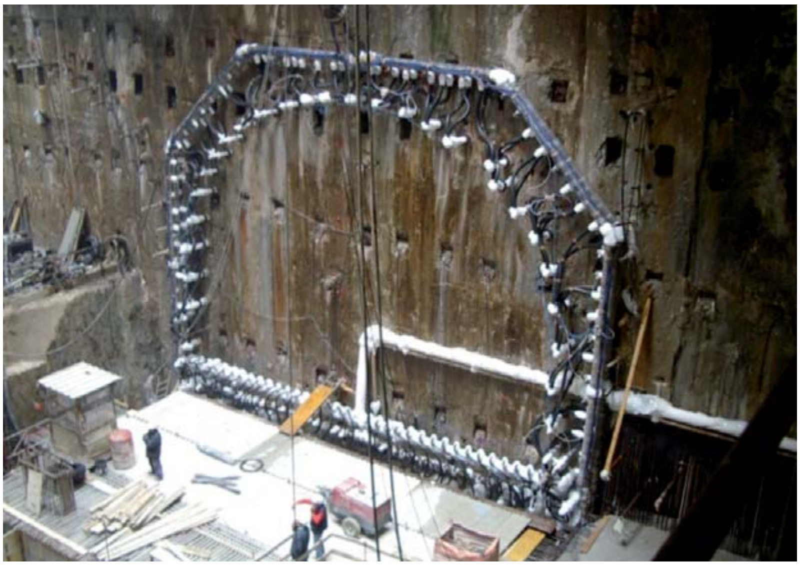


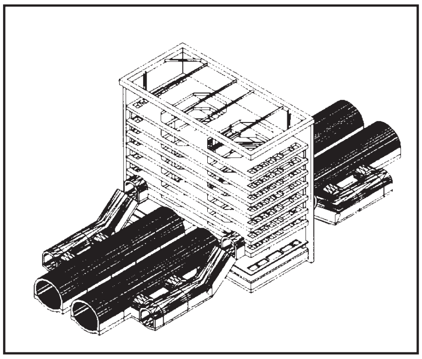
Tunnel section - Plan view
The truncated cone-shaped excavations are highlighted

TDDT drilling

Tunnel section - Plan view
The excavation section is the same throughout the length

Case studies





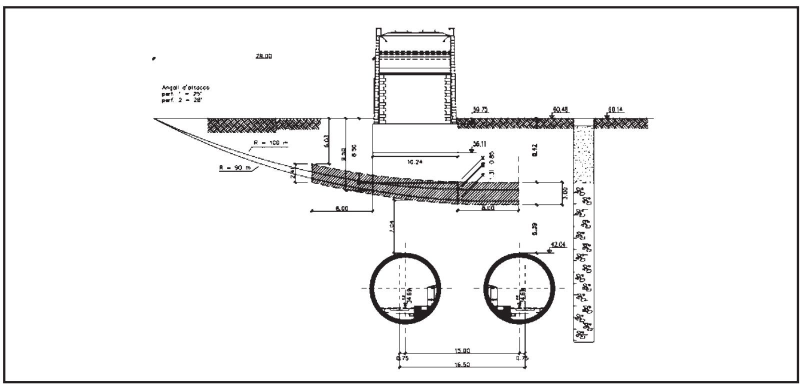
NAPLES underground (Italy)
Underground station

- P.zza Garibaldi station
- Toledo station
- Università station

The project for the construction of the tunnels of Piazza Garibaldi station for the new underground in Naples envisaged ground freezing of a 50 m-long stretch to be made in one single step.

To ensure homogeneous ground freezing, it is essential to keep the same distance from one freezing pipe to the other throughout their length: they shall never diverge beyond the tolerances set in the project *(in this case, the allowed deviation was about 0.5%)*.

As traditional drilling techniques did not ensure the required accuracy, TREVI decided to use directional drilling by adapting it to an operational situation requiring for blind holes to be drilled from the shaft, with high water head. The drilled boreholes allowed to install the freezing pipes with the desired accuracy; the project was completed with no problem.



High speed railway line
BOLOGNA (Italy)

The high speed rail link was supposed to reach the highly urbanized area of Bologna city, in the areas where the tunnels excavated by TBM interfere with some existing structures. As a result, the project envisaged the use of the “compensation grouting” technique to monitor and compensate any soil settlements generated by tunnel construction.

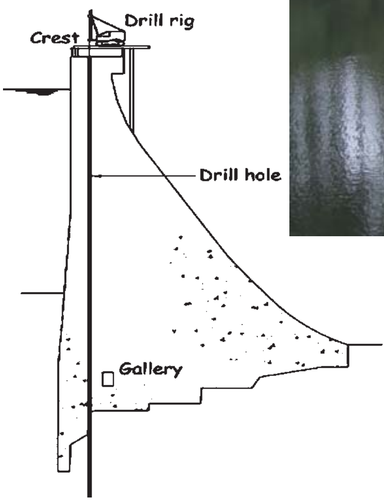
Originally, it was decided to start from three shafts next to the structure, but the shaft construction was prevented by the limited space and some problems faced in making those areas available.
To resolve the impasse, TREVI proposed to carry out drilling from surface, using the curvilinear guided drilling technology. In this case, a minimum distance of 25-30m from the structure was maintained, to respect the minimum radius of curvature allowed by the drill string, starting with a 30° inclination from surface to reach horizontal position at a depth of about 11 m.

Roughly 150 TAMs of 50mm were installed underneath the foundation area of the piers of Ponte Vecchio, and 46 TAMs under the bridge in Via Rimesse, accounting for 7,530 metres in total.
The maximum drilled length was 68 metres, with an average of 52 metres.

Case studies

ARAPUNI dam
(New Zealand)

For the rehabilitation works of the Arapuni dam in New Zealand, a cut-off wall of secant piles was constructed down to a depth of about 95 m. About 200 piles were drilled using an innovative technique: pilot holes were drilled first, and then reamed out to full diameter. The exceptional pile length and the presence of a tunnel at the base of the dam made it necessary to use directional drilling technology.
The pilot holes were made by drilling about 60 metres of the dam body and penetrating further 40-50 metres through the fractured ignimbrite rocks underneath.
The subsequent reaming to a 400mm diameter allowed to drill the secant piles which were later backfilled with concrete to create a cut-off wall.



Conte di Troia and Pariti 1 landfills MANFREDONIA (Italy)

Located where pre-existing calcarenite caves stood, the landfills of Conte di Troia and Pariti had to be reclaimed to prevent leachate percolation through the soil underneath them.
The project envisaged the realization of a bottom plug and a hydraulic perimetral barrier, by means of cement and silicate mix grouting.

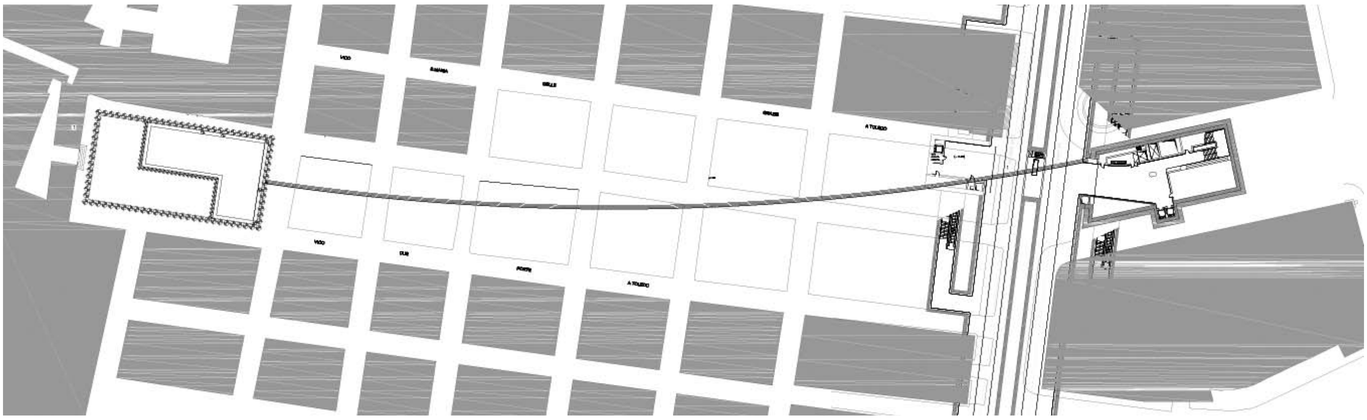
For the bottom plug alone, about 700 curvilinear sub-horizontal drillings of a max length of 140 metres were made. They were all made outside the landfill area and max deviation from project path was 0.25 metres.

The total drilled length reached roughly 60,000 metres.

Case studies

Connection between the Bovio and Montecalvario shafts NAPLES underground (Italy)

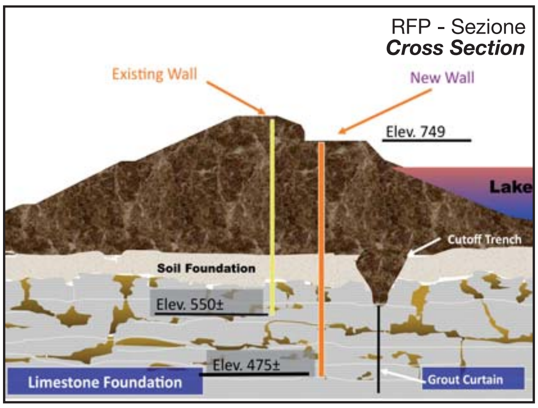
To solve the challenging lack of space for jobsite installations, the Bovio and Montecalvario shafts used a single plant for grout preparation. To transfer grouts and water, a borehole was drilled to fit the necessary pipes.
The borehole *(shown in red in the figure)* was curved both horizontally and vertically. It was 194m long and had a diameter of 160 mm.



WOLF CREEK dam KY (USA)

In order to stop seepage below the Wolf Creek dam in Kentucky, the USACE (US Army Corp of Engineers) decided to build a concrete cut-off wall into the very hard limestone (UCS up to 200 MPa). The remedial works combined secant piles and panels drilled by hydromill, for the construction of a continuous plastic concrete wall of a thickness of at least 600 mm, down to a depth of 84 m, covering a total surface of about 100,000 sq.m.

Due to the high depth and tolerances set by the project (± 100 mm), it was necessary to drill directional pilot holes. Reaming of the pilot holes was carried out by reverse circulation system up to a diameter of 1.270 mm.

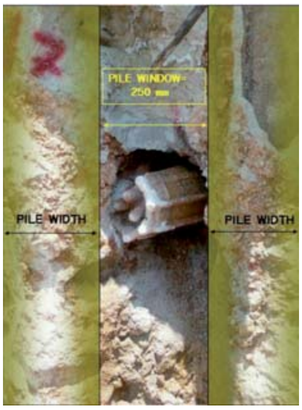


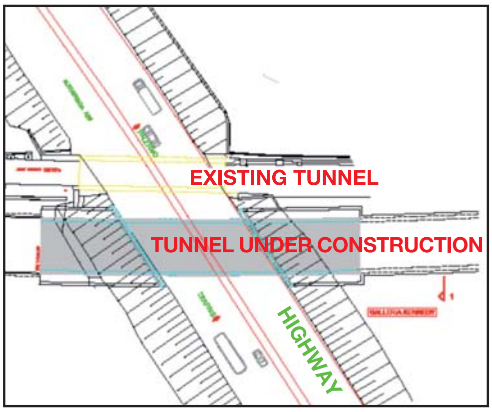
Case studies

PALERMO underground (Italy)

To bore a tunnel aimed at doubling the Palermo Centrale/Brancaccio – Carini line at the junction with the A29 motorway, it was decided to consolidate the volume of the motorway embankment to be crossed, by installing tubular reinforcement elements (connected 160mm-diameter steel tubes). Moreover, connecting elements (Dywidag bars) were driven between the soldier piles walls previously constructed.
To make it possible to expose the excavated face between the nearby beams of the soldier pile walls, a positioning accuracy of ± 50 mm had to be guaranteed.

The 30 m-long horizontal drilling was steered using magnetic and optical guidance systems.





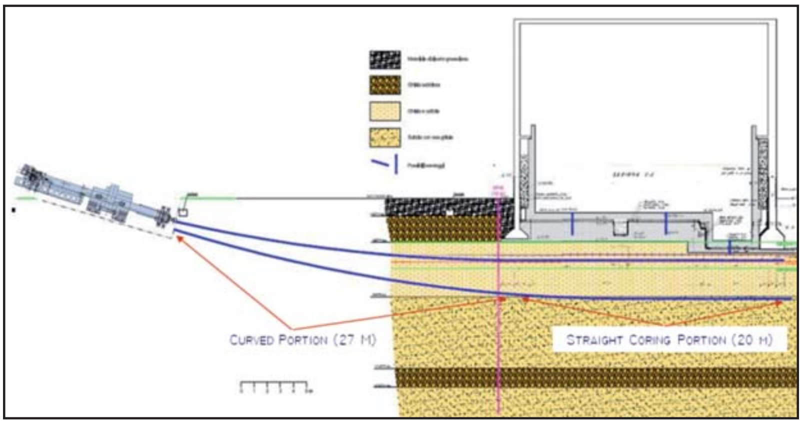
ENEA plant*
Saluggia (Italy)

The EUREX plant for nuclear fuel reprocessing is located in Saluggia, at about 45 km from Turin on the left bank of the Dora Baltea river. Due to a suspected water leakage from a storage tank and the consequent fear of soil contamination beneath it, soil sampling was carried out underneath the tank.

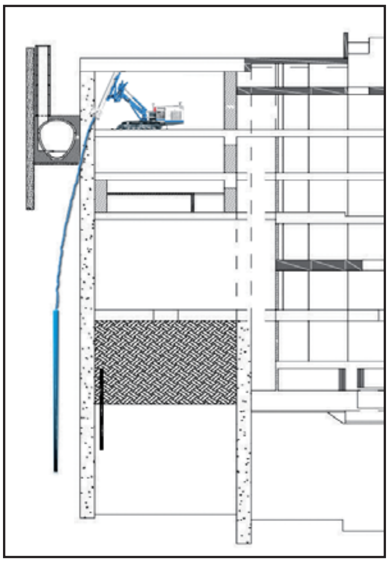
Enea requested 4 horizontal investigations to be carried out in the soil under the tank, as well as sampling above and below the piezometric line. A distance of at least 20 m from the plant had to be maintained, with a max deviation of 300 mm from the project values.

Sampling was made using curvilinear drilling with magnetic guidance system, for a max length of 50 metres.

** The project has been designed by SOGIN and completed by RCT in conjuction with Trevi.*



Case studies

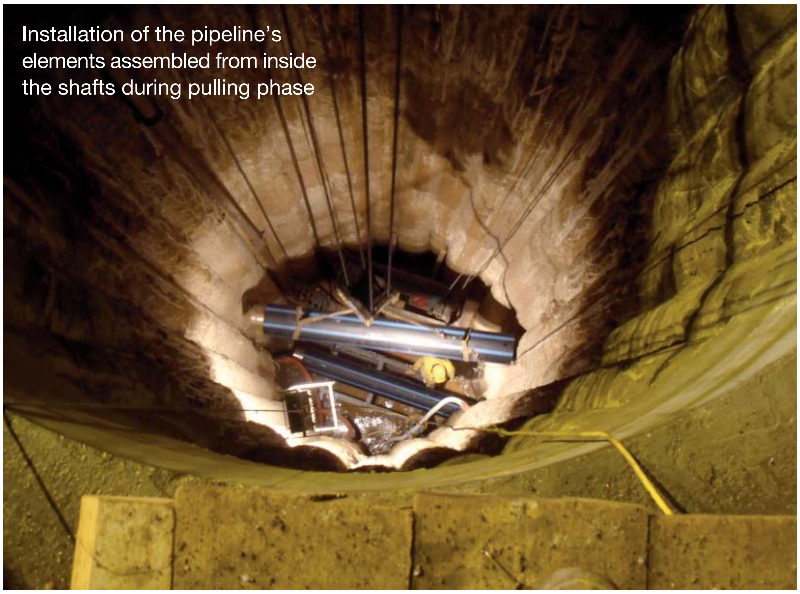


Underground metro station (Italy)

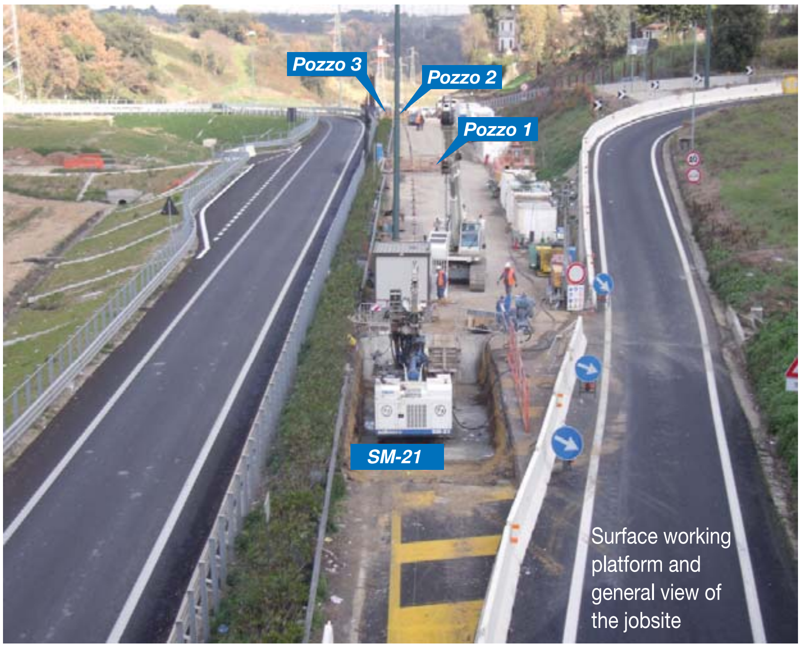
An underground station for a metro railways was built, using diaphragm walls panel up to a depth of 56 m. While sinking the shaft using the top-down method, some misalignment of panels were discovered, raising the concern about a potential problem of water-tightness.

Therefore it was decided to precautionarily waterproof the area next to some joints of the diaphragm wall by grouting. As it was impossible to install the TAMs from surface, it was decided to fit them inside boreholes drilled inside the station from an intermediate level underneath the road surface.

Curved guided boring had an average length of 36 m and a 70m radius of curvature.



Installation of the pipeline's elements assembled from inside the shafts during pulling phase



Surface working platform and general view of the jobsite

Cassia tunnel Rome (Italy)

Within the framework of the works carried out to widen Rome's ring road (Grande Raccordo Anulare) to three lanes a permanent drainage control system was designed and completed for the slope facing the new Cassia Tunnel.
The method adopted for the execution of the drainage system avoided the need for drilling works to be performed from inside the drainage wells, resulting in considerable benefits for logistics and safety.

The method, alongside the confined site areas and the fixed location of drainage shafts, induced the designers to opt for the CSP (cased Secant Piles) technique for the installation of three shafts (3.5 m diameter), from which small diameter horizontal drains shall be drilled. Due to the distance between the drainage shafts and between the last one and the catchment tank, directional drilling was adopted for the necessary links.
The drill rig used for drilling and pulling the pipe (D 400 mm) was a Soilmec SM-21, which ensures great flexibility in positioning as well as the required crowd and torque values.
The accuracy demanded to respect inclination was considered as +/- 0.1°, whereas the one needed for the well entry to ensure easy fitting of the 3m-bars was judged +/- 0.2 m in positioning and +/- 1° in the entry direction. A Paratrack® steering tool was adopted for both stretches, creating an artificial magnetic field on surface.

Both the project accuracy and viability of the methods adopted confirmed the reliability of such an innovative technology for the deep drainage of slopes and landslide-prone areas. The works underwent an inspection by ICIC that granted TREVI Spa the integrated certificate for "Works in confined space" and for the realisation of catchment and drainage works in wells in compliance with ISO 9001, ISO 14001, OHSAS 18001.

TDDT 001/06/2013 UK

World leader in ground engineering, Trevi has been working for more than 50 years throughout the world, strengthening its ability to provide solutions to any ground engineering issues.
Trevi works in the field of special foundation, soil consolidation, dam remedial works, tunnel construction and consolidation, marine works, rehabilitation and cleanup of contaminated sites and construction of underground automatic multi-storey car parks.
Trevi is committed to continuous innovation and search for solutions to complex problems of civil engineering worldwide.
Experimenting cutting-edge technologies, entrepreneurship and investing in research and human resources are the strengths of a company based in more than 30 countries.

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