TECHNOLOGY

Injections

TREVI

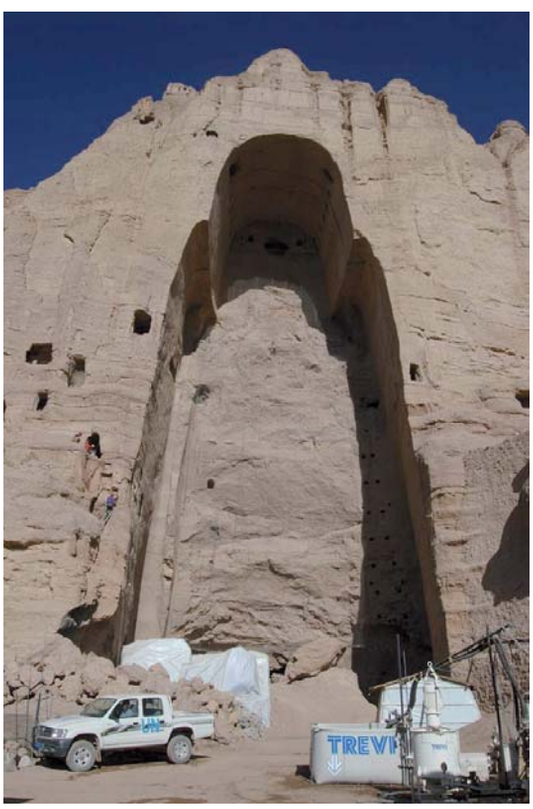
Technology

Injection technique is used in civil engineering to improve the mechanical and permeability properties of soil, rocks and brick or concrete work.

From a functional point of view, two types of interventions can be identified:

- **temporary intervention**, to make excavation possible in unstable soil or under water table;
- **permanent intervention** for the consolidation of foundation soils, the creation of watertight structures, or the structural restoration of brick or concrete works.

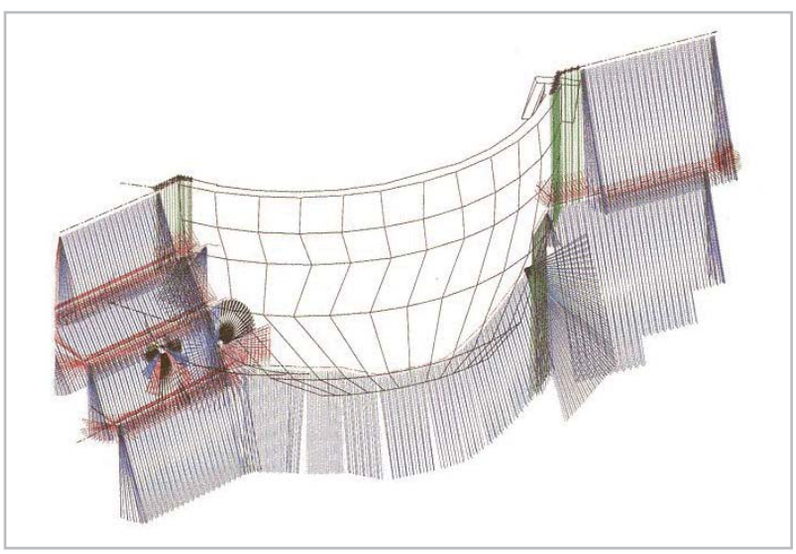
Temporary injection - Milan Underground, Line 3. Waterproofing and consolidation injection.



Permanent injection - Bamiyan, Afghanistan. Consolidation injections of the rocks of the niche of the Great Buddha.

Temporary injection - Naples Underground, Toledo station. Pre-consolidation and waterproofing injections of the service tunnel.

Permanent injection - Tower of Pisa. Consolidation injections of rubble masonry.

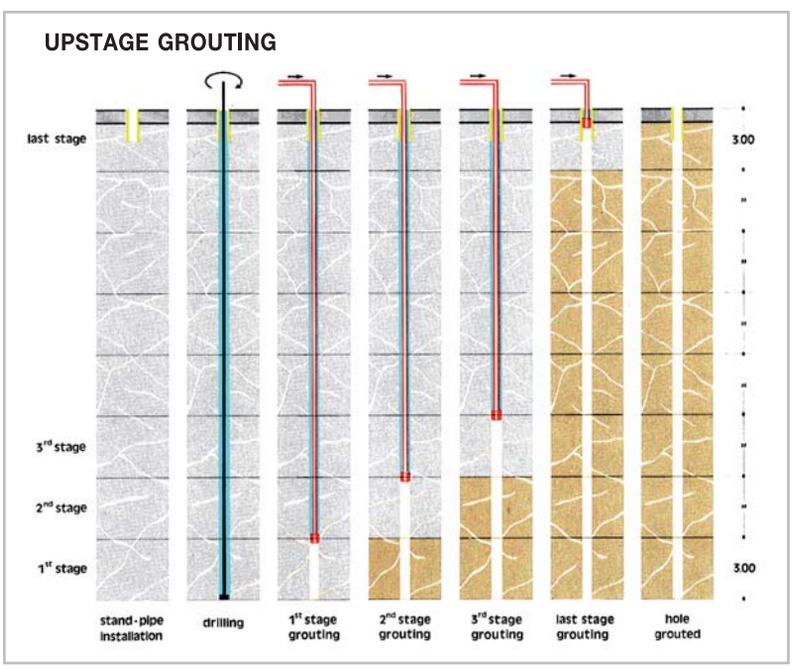


Permanent injection - El Cajon Dam, Honduras. Waterproofing injection for the creation of a cut-off wall around and underneath the dam.

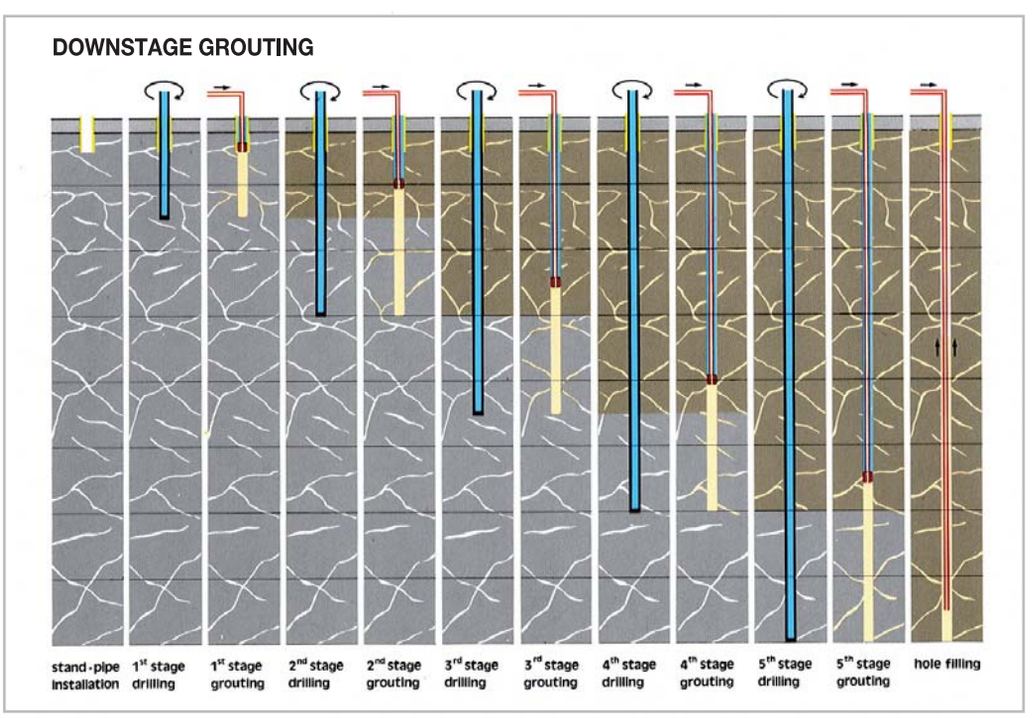
Grouting systems
Systems with packer in bedrock

	ROCK				SOIL		
	STABLE	UNSTABLE					
	OPEN HOLE		MPSP	DRILL ROD		SLEEVE PIPE	LANCE OR CASING
SINGLE STAGE	●			●	●		●
MULTI STAGE			●			●	
ASCENDING ST.	●		●	●	●	●	●
DESCENDING ST.		●	●			●	●

Classification of grouting systems according to the European Standard EN 12715 'Grouting', Chapter 8.4, table 4)



Upstage grouting with packer in rock formation ***(ascending or up-stage)***



Downstage grouting with packer in rock formation ***(descending or down-stage)***

From an operating point of view, grouting is divided into loose soil grouting and in rock grouting.

Rock fissure grouting is performed directly into the open borehole. In this case, downstage or upstage methods can be used.

- With the *upstage* method (also named *'ascending stage'*), the borehole is drilled at the project depth; then selective upstage grouting by areas is carried out using a specific single packer that breaks up the borehole in a number of lengths. Due to the aforesaid procedure, this method is suitable for grouting in boreholes that remain stable throughout significant lengths, with no drilling slurries or temporary casings.

- In case of unstable boreholes, the *downstage* method is preferred (also named *'descending stage'*): a length of borehole is drilled, then the tool is raised for a few meters and grouting is performed. Before re-drilling the injected length and repeating the procedure for the following length it is necessary to wait for the mixture to harden.

In both cases, borehole inclination must be defined depending on the position of soil layers and the direction of discontinuities, so as to affect the highest number of joints or fissures.

Grouting systems
MPSP and TAM

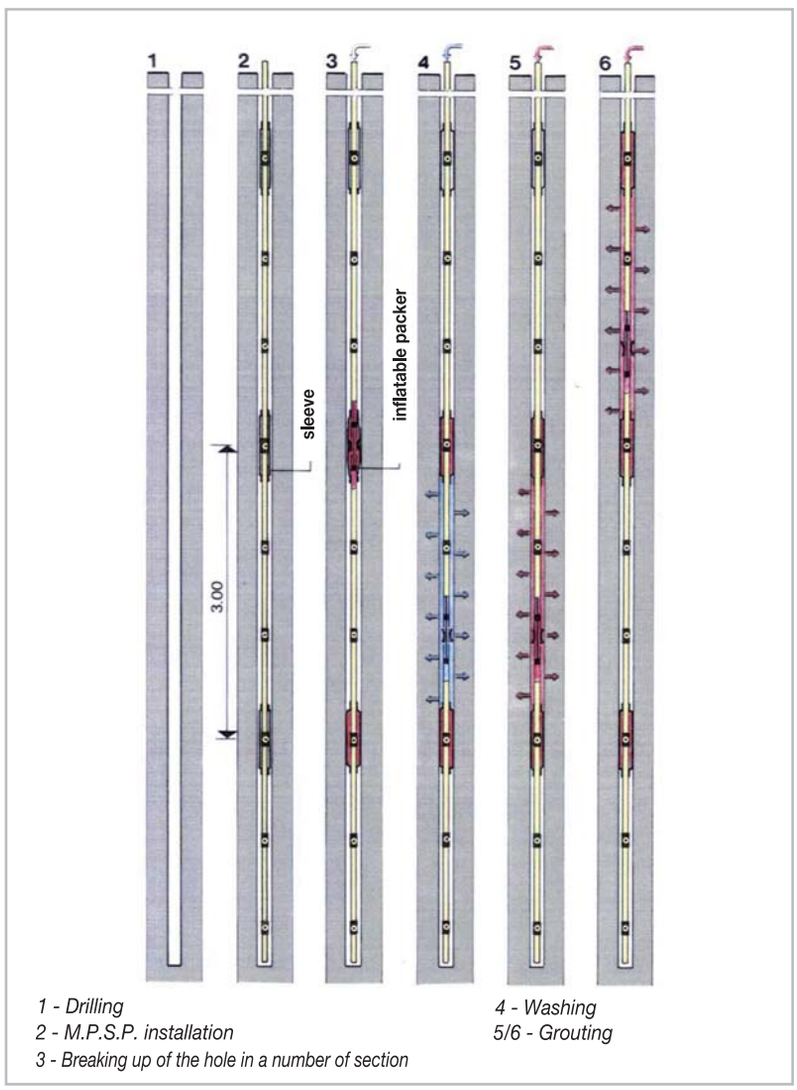
Grouting in **weathered rocks** or **loose soil** can be performed by using tubes fitted with check valves, which are driven into the ground after drilling. The valves are usually rubber sleeves that cover lengths of the tube featuring holes: they inflate under pressure and force the grout through the holes preventing it from flowing back.

Grouting is performed by isolating the tube lengths by means of an inflatable double packer. In particular the following methods can be used:

- **MPSP method** (*Multi Packer Sleeve Pipe*), designed and developed by RODIO-TREVI to treat weathered rocks.
- **Manchette tube** (*'Tube A Manchette'* **TAM**), sealed to the soil by means of a sheath grout for loose soil permeation.

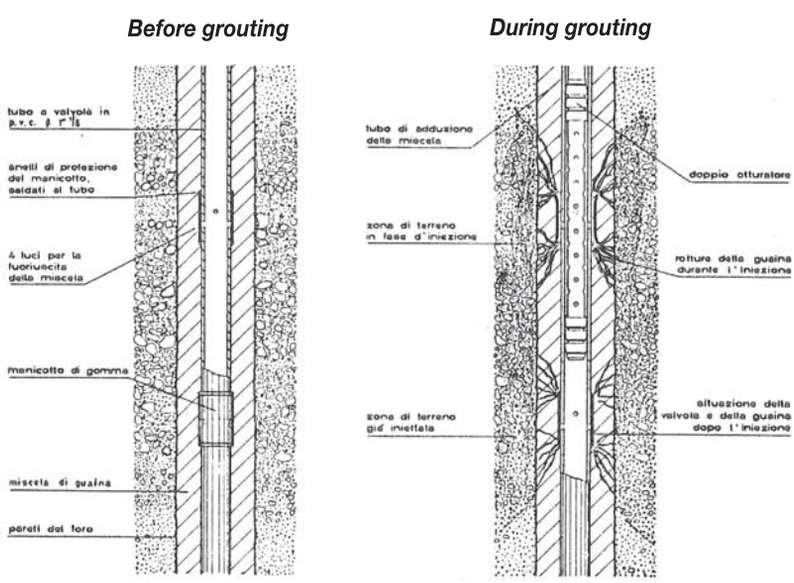
Manfredonia, Landfill of Conte di Troia (2010)
Waterproofing injections in rock formation: MPSP installation and grouting

Rome underground: Line C (2010)
TAM grouting in loose soil



1 - Drilling
2 - M.P.S.P. installation
3 - Breaking up of the hole in a number of section
4 - Washing
5/6 - Grouting

*Operating scheme of **MPSP** grouting in rock formation*

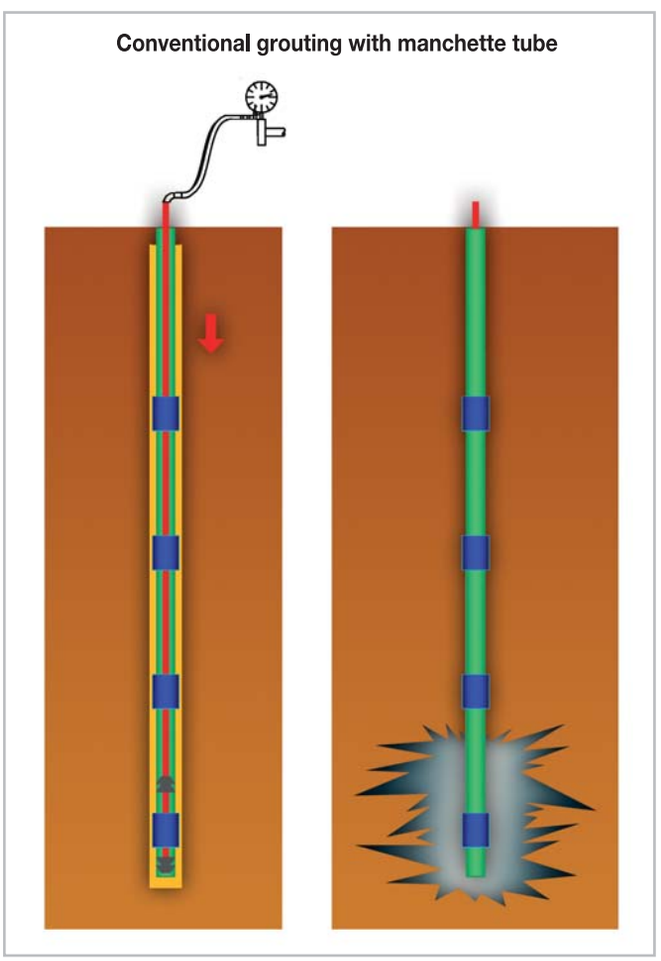


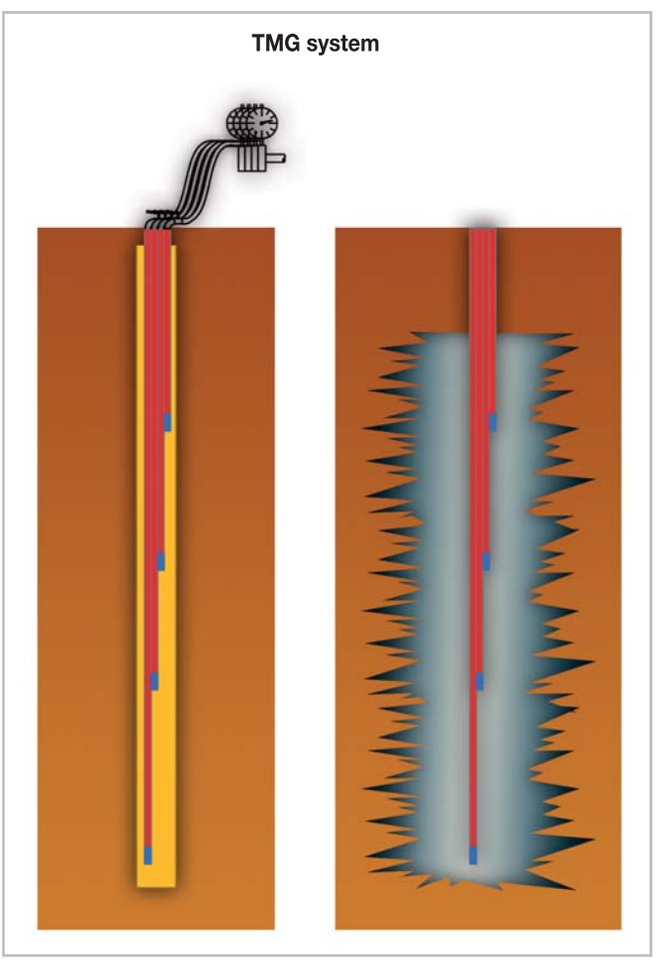
*Operating scheme of **TAM** grouting in loose soils*

Grouting systems
TMG (Trevi Multi Grouting)

To grout fine-grained soils, Trevi has designed the **TMG system (Trevi Multi Grouting)**: a group of small-diameter tubes with different lengths and fitted with one single valve are inserted into each hole.
Every tube is directly connected to the grout delivery line, with no need for sliding the packer down into the hole. In this way it is possible to grout different levels of the same borehole simultaneously and in a selective way *(with different preset parameters)*.
The tubes *(with high burst strength)* have different colours, each being also identified by a progressive number associated with the valve depth. To inject many tubes simultaneously, special plants with tens of low flow rate pumps are used, each being connected to the device controlling and recording the parameters of grouting.

Depending on the type of soil to be treated (level of fissures/porosity) and the intervention requested (consolidation and/or waterproofing), a specific project is prepared to define the distance between the holes, the most suitable grout and the grouting parameters to use.
The grouting parameters (volumes, pressures, flow rates) are constantly controlled and recorded during every grouting stage. The outcomes are processed and analysed in order to assess the effectiveness of the treatment carried out so far and manage the following stages in the best way possible.





TMG system: grouting through single-valve tubes

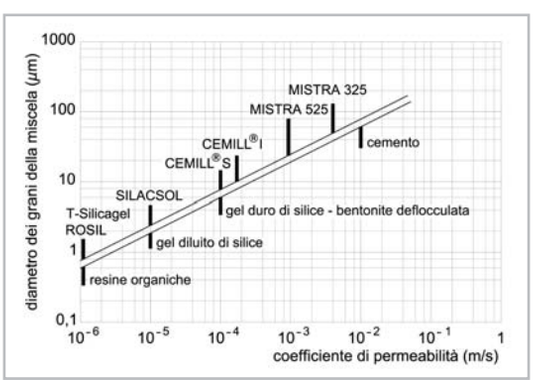
Grouting mixtures

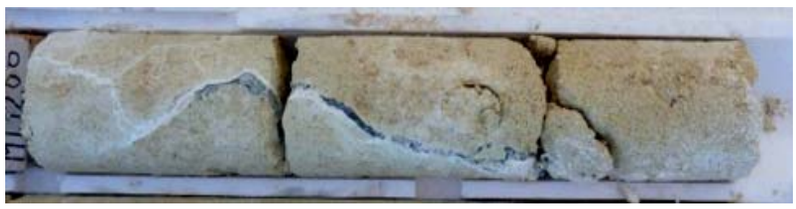
Cement-based grouts are usually the choice for rock formations or loose coarse-grained soils.

Cement grouts can be stabilized by means of pre-hydrated bentonite, whereas they are made less cohesive and more fluid by adding special formulations and deflocculating-fluidifying additives ***(MISTRA grouts)***.

There is evidence in literature that successful grouting depends in the first place on the size of the solid particles of the injected grout compared to the dimensions of the gaps or rock fissures to be injected.

- For the injection of slight rock fissures and finer-grained soils, fine cement or micro-cement grouts are recommended.
- For the **injection of fine-grained soils or rock micro-fissures**, it is possible to use **Silicate-Mineral** based grouts **(SILACSOL)**, which ensure good results both in terms of consolidation and waterproofing, or "soft" Silicagel for waterproofing only.
- For **even finer soils**, the use of colloidal silica can be envisaged (nano-silica). Since some time now, Trevi have designed a nano-silica based grout in colloidal aqueous solution with no addition of mineral agents or insoluble salts ***(ROSIL grouts)***.
  Rosil grouts are injected in one single phase, by adjusting the setting time through the dosage of inorganic salt.
  Once injected, Rosil grouts harden and create a stable product free of syneresis.
- On the contrary, to fill cavities or high porosity formation, **expanding grouts** can be used.
  Expanding cement grouts are standard stable cement-based mixtures in which an agent is added to generate micro-bubbles that remain entrapped within the mix and expand it.
  Initially the mix looks like a standard grout, easy to pump. Then it expands and turns into a rigid foam. Expanding grouts can be usefully exploited in a number of applications: filling large natural or artificial cavities, filling and re-compressing soils hit by landslides, contact grouting of tunnels, etc.

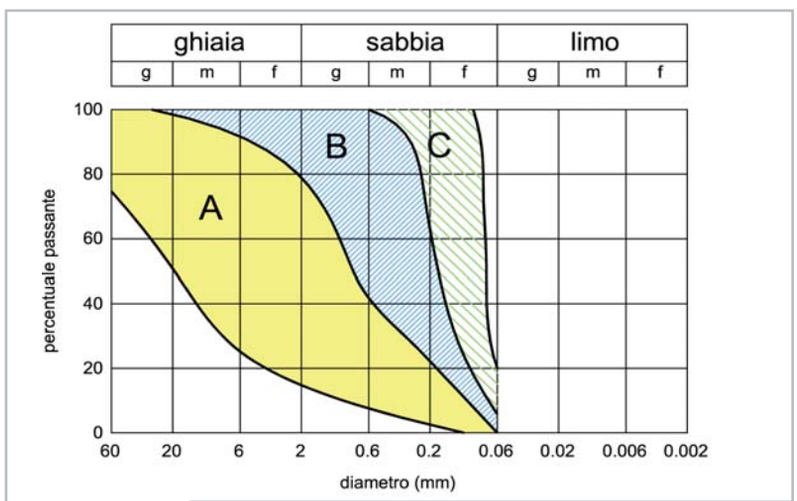




MISTRA and SILACSOL grouts injected in calcarenite (Landfills of Manfredonia, 2010).

Cement grout injected in the joints of limestone formation (Bari, underground car park in Piazza Cesare Battisti, 2007).

SILACSOL grout injected in tuff (Naples underground, 2007).



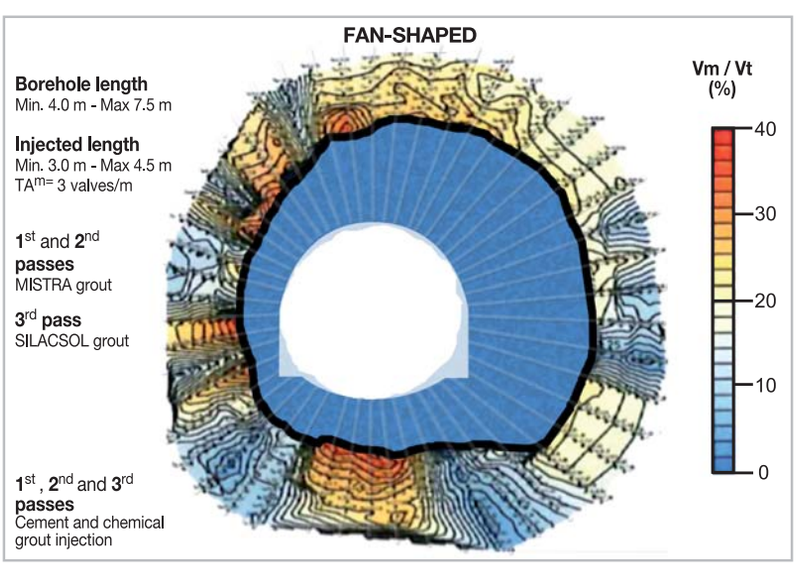
campo granulometrico	effetto di permeazione		
	miscela MISTRA	SILACSOL	ROSIL
A	da ottimo a discreto	ottimo	=
B	da discreto a scarso	ottimo	ottimo
C	=	discreto/scarso	ottimo

Grouting plants and parameter control

Grout preparation plants

SOILMEC SGJ-8 grouting plant

GPC: data input and parameter controls during execution



GPC: Example of graphical representation of the parameters

Grouts are prepared and pumped by means of specific mixing and pumping plants. The storage, dosing and mixing plants can include a number of equipment for the preparation of different types of cement or chemical mixes.
Grouting plants include agitators in which ready-to-inject grouts are stored. They feed the pumps and injectors to inject the grout into the borehole, which can be a few hundred metres away.

Grout delivery pipes under pressure

Trevi have designed, manufactured and improved in-house a computerised system for automatic control, data acquisition and automatic recording of grouting parameters *(GPC Grouting Parameter Control)*. The system consists of a number of sensors installed on the injectors *(at the main plant or borehole mouth)* and by a computer with software.
The computerised system allows to prepare a 'Project' detailing the grouting parameters to be implemented for every single valve/stage for every borehole. Sensors, flow-meters and digital pressure gauges measure the applied parameters in real time. These values are sent to the central system, which records and process them, and monitors grouting, by automatically controlling the operation of the injectors.

This system is capable of

- **maintaining the operating parameters within the limits set by the technical specifications**, based on the data as they are acquired;
- **automatically adjusting the said parameters depending on the answer to treatment**, measured in the soil and surrounding area;
- **automatically adjusting the said parameters depending on the answer to treatment**, measured in the soil and surrounding area.

By controlling the whole grouting process, it is possible to automatically adapt injection to the geotechnical features and the data measured while working, ensuring at the same time high quality of treatment and simplified process management.
Furthermore the system allows to prepare tables and plots with the data, in order to analyse and document the works carried out.

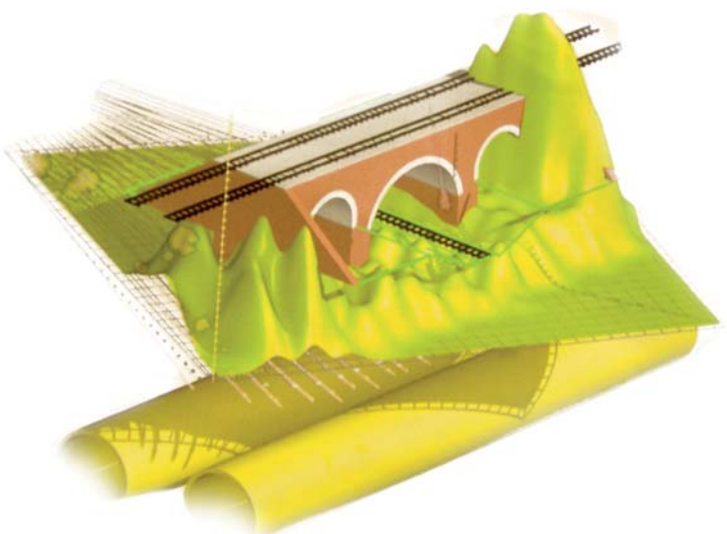
Compensation Grouting

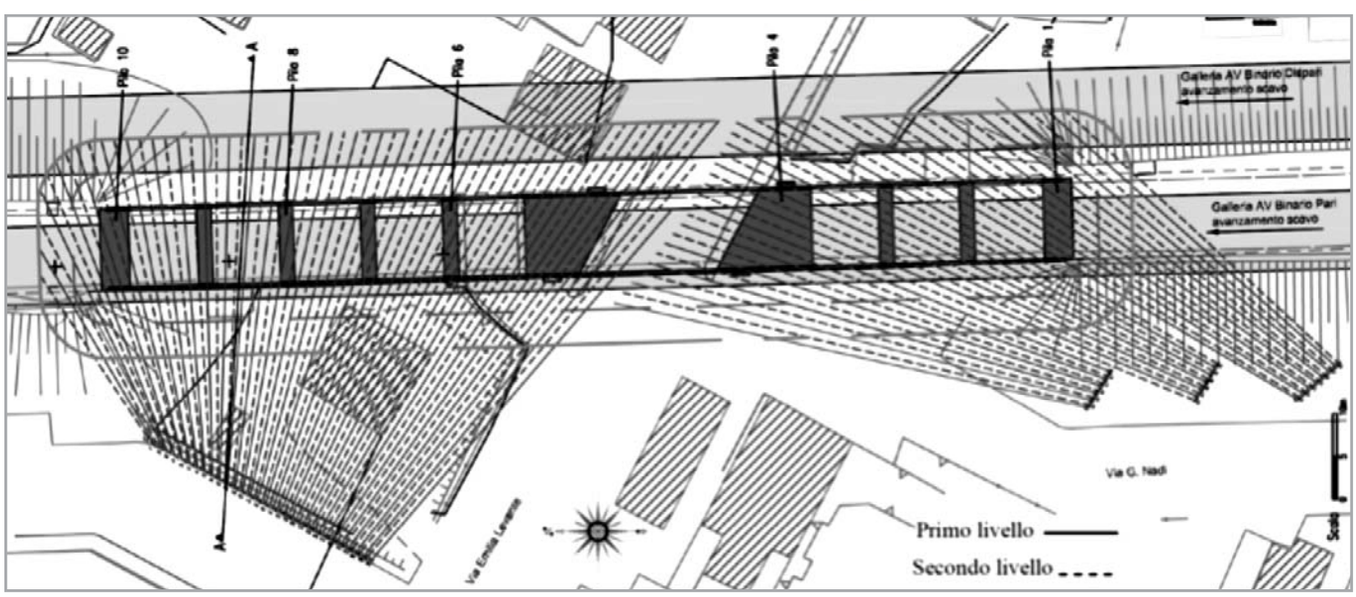
Tunnelling and underground excavation under a thin cover between the tunnel roof and ground surface inevitably cause subsidence and therefore damage to the overlying buildings. To mitigate or eliminate the effect of subsidence, **Compensation Grouting is used.**

The main idea of Compensation Grouting is to inject grouts into the soil between the tunnel and the overlying structure at risk, in order to offset the settlements caused by tunnelling, through induced and controlled raising.
To this end, grouts are injected at relatively high pressure to displace the soil. Fracture grouting or compaction grouting can be implemented. In practice, low mobility grout mixes are injected in a selective and repetitive way, through sub-horizontal pipes fitted with valves and properly positioned and spaced.

The boreholes for grouting pipe insertion are usually drilled starting from a shaft close to the building under which injection is implemented.
Alternatively, curvilinear drilling can be the choice to perform drilling from the surface and reach a preset depth. In both cases, directional drilling is used, to ensure grouting pipes are properly and accurately positioned, even in case of long distances. Sensors are installed in the proximity of the building to monitor any induced deformations: settlements caused by excavation and raising caused by injection. All the data gathered are sent to a computer, which manages and displays data in real time: in this way it is possible to follow the evolution of works and, if needed, correct or stop injections by observation.

Milan-Naples high speed train, Bologna hub - San Ruffillo jobsite (2005)



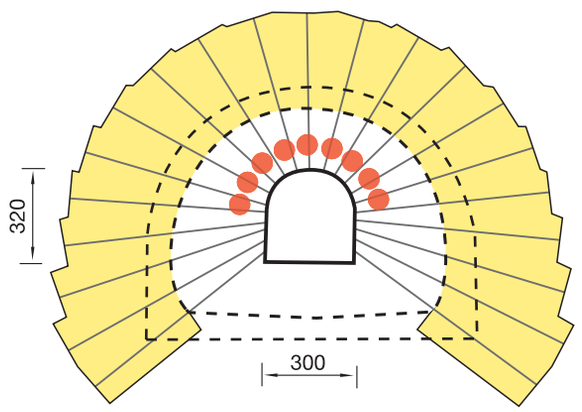


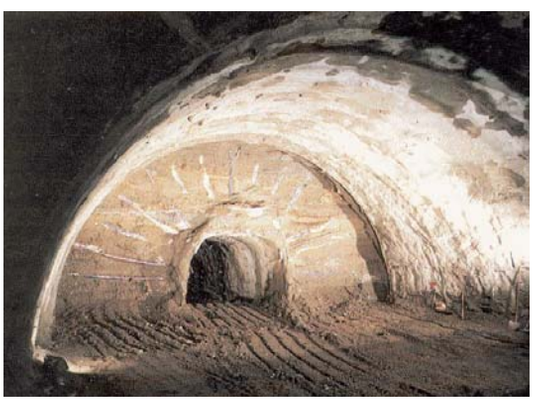
Bologna hub, San Ruffillo jobsite: plan of the viaduct with marking of tunnels and grouting pipes.

Examples of applications

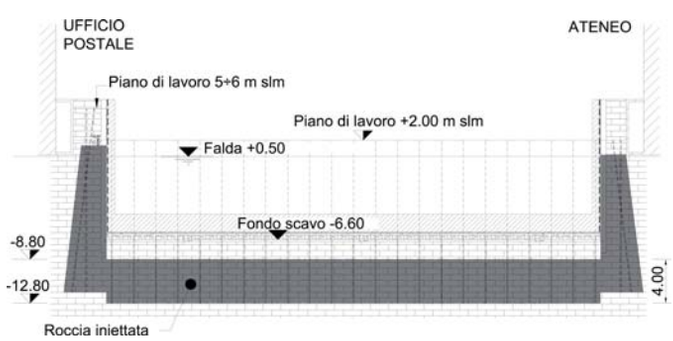
Injections can be used for interventions aimed at improving the foundation soil and rocks of new buildings, such as:

- **Consolidation and/or waterproofing of soils and rocks before tunnelling or subway excavations**
- **Realisation of watertight bottom walls to allow for excavation under water table**
- **Realisation of cut-off walls under new dams**
- **Foundation soil consolidation of new structures or buildings**

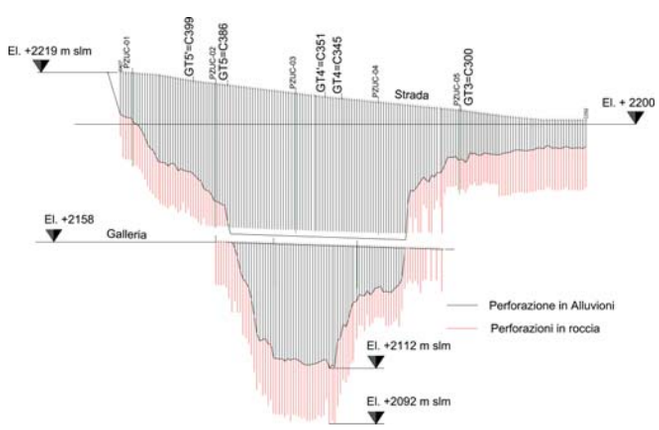




Milan underground, Line 3 (1985/88) – Soil waterproofing and consolidation treatment from cross passage.



New car park in Piazza Cesare Battisti, Bari (2006/7) – Injection of limestone in Bari to allow for excavation under water table and close to adjacent historical buildings



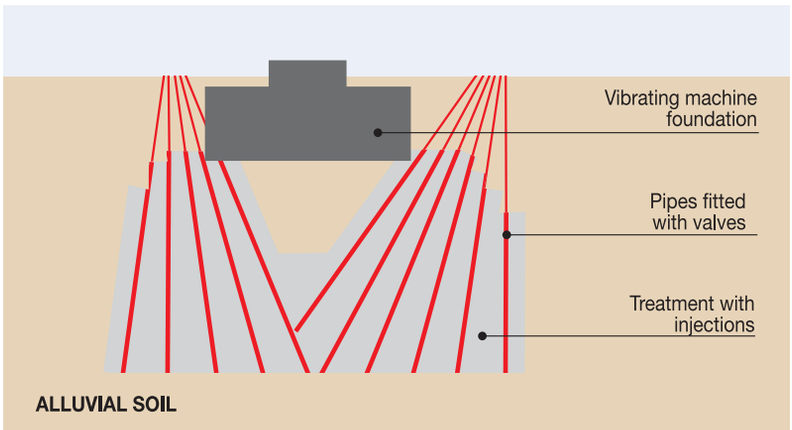
Parbati Hydroelectric Project, Himachal Pradesh, India (2006-2008) – Waterproofing injection for the construction of a cut-off wall in the Paleo riverbed

Examples of applications

Injections are also suitable for the restoration, retrofitting or upgrading of existing buildings to safety standards.

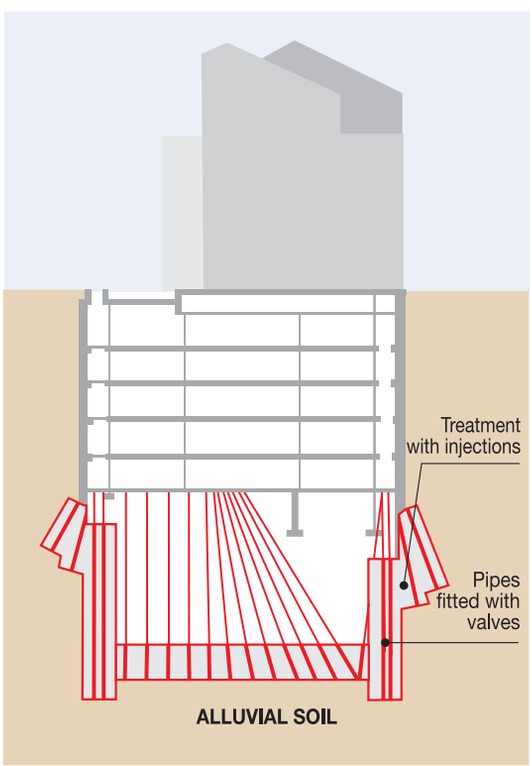
A few examples are given in the following list:

- **Restoration of existing foundations (1)**
- **Functional adaptation of buildings (2)**
- **Recovery of sunken areas under the water table (3)**
- **Interventions on existing dams, with the construction or integration of cut-off walls (4) or sealing of fissures in the dam body (5)**
- **Restoration and adaptation of tunnels (6)**
- **Construction of impervious barriers below contaminated areas (7)**

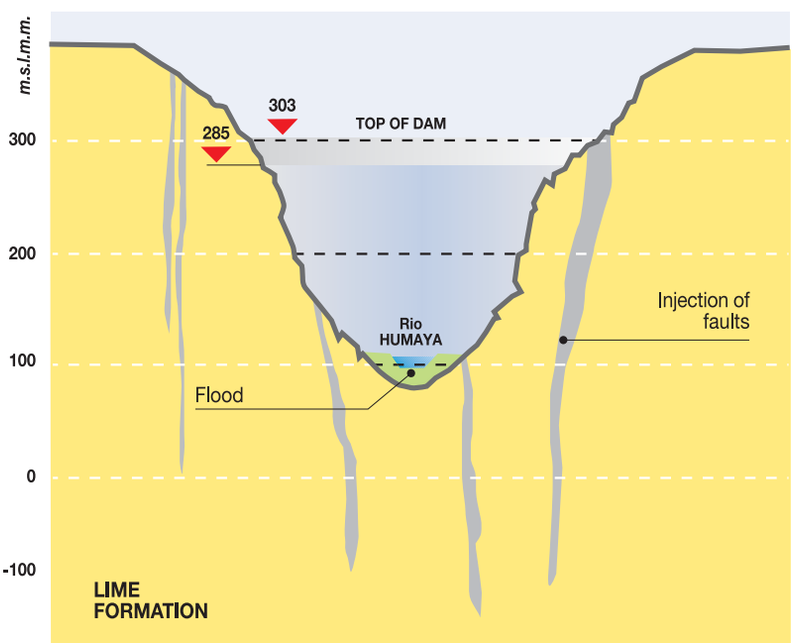


1 - *Villesse (1992): consolidation injections in the foundation soil of vibrating machinery by means of permeation grouting in loose sands and gravels.*

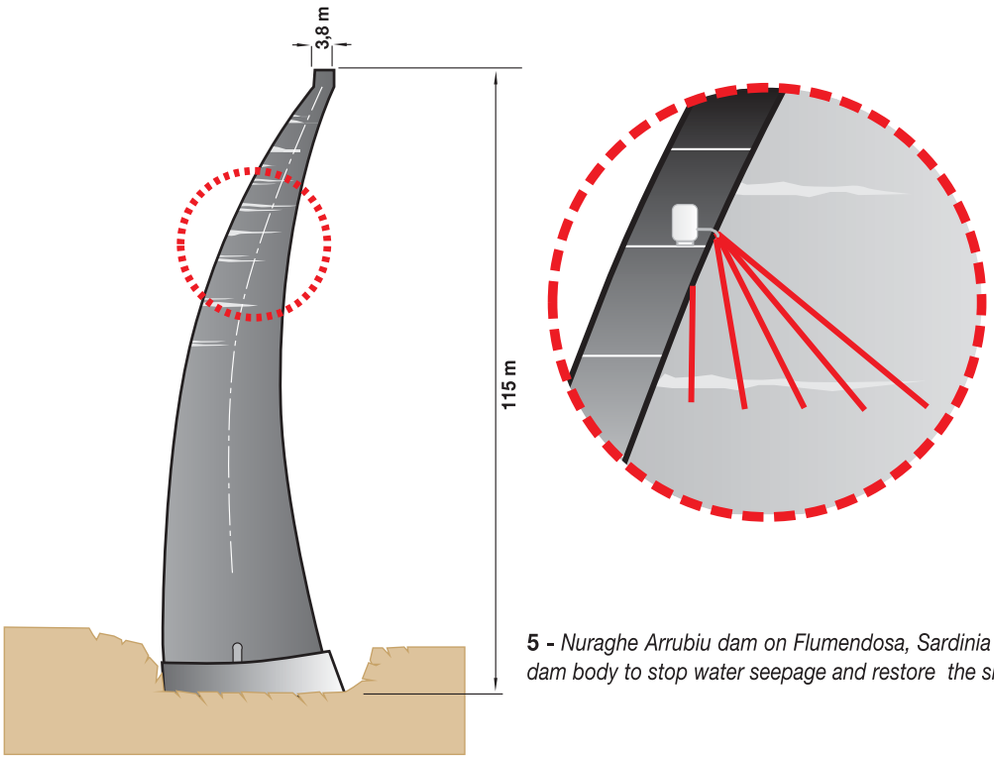
2 - *Petruzzelli Theatre, Bari (2004): structural and architectural restoration works - Excavation under the water table with consolidation and waperproofing grouting.*



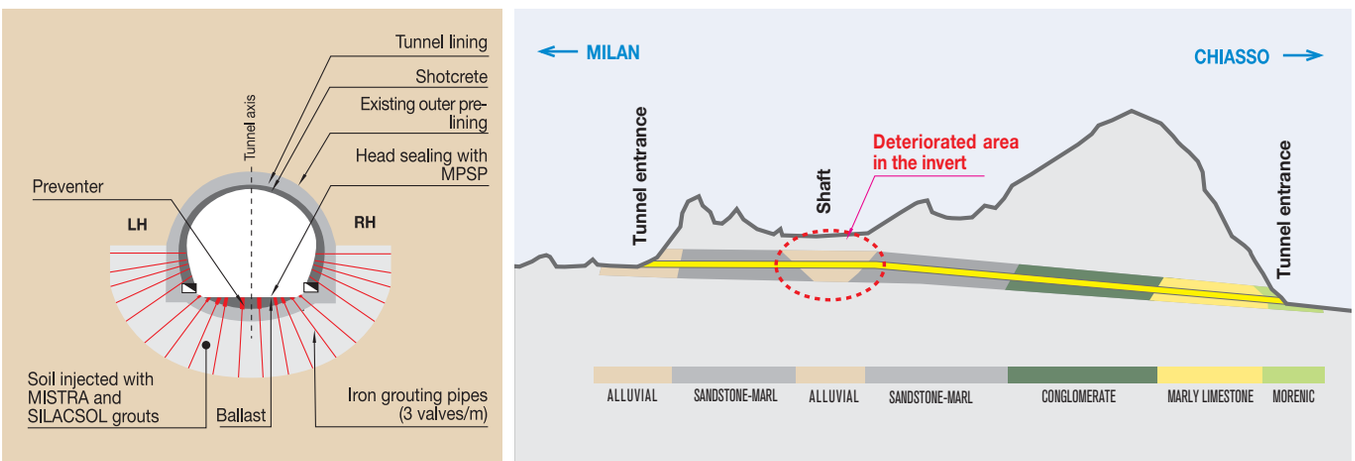
3 - *Building, Via Borgospesso, Milano (1994): works for recovery of the 6th underground floor, flooded because water table raising.*



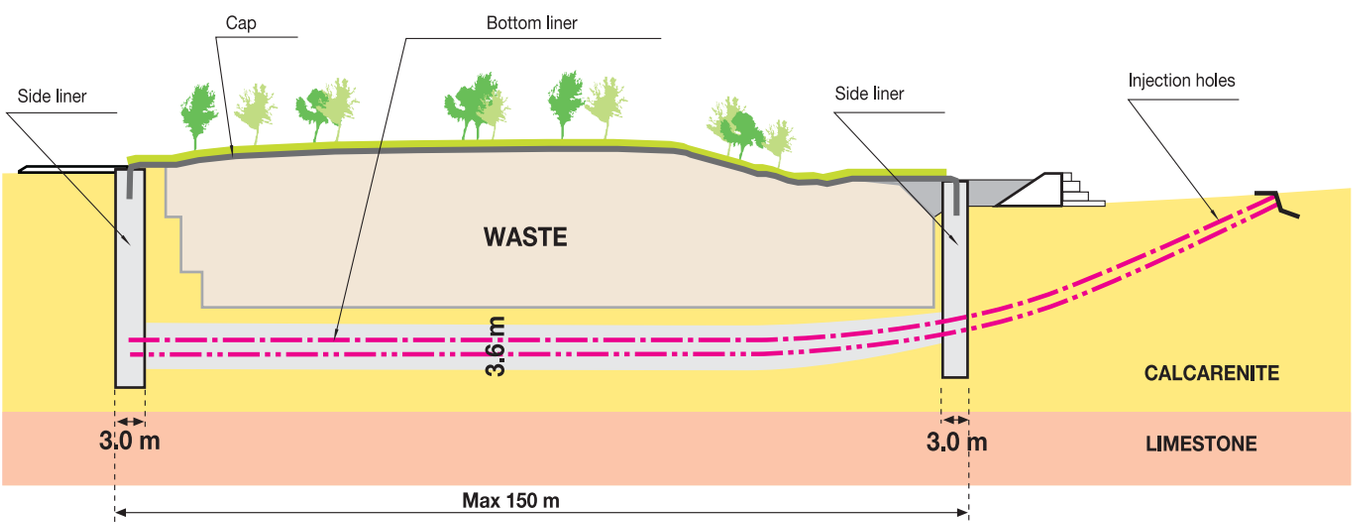
4 - *'Francisco Morazan' dam, El Cajón- Honduras (1992-1996): integration and restoration of the existing injection screen. The 226m high arch dam is made of concrete. It lays on limestone characterized by karst phenomena and crossed by 4 series of faults.*
After dam filling, the clay materials in the 4 faults had been locally eroded, thus increasing water seepage.
The grouting treatment performed from the cross passages with full dam (water head up to 180 m, holes up to 250 m depth, with preventer) resulted in a reduction of total water seepage flow rate from about 1600 l/s to 88 l/s.



5 - *Nuraghe Arrubiu dam on Flumendosa, Sardinia (1994) – Epoxy resin injections into the dam body to stop water seepage and restore the single-piece concrete nature of the dam.*



6 - *Milan-Chiasso railway line - Monteolimpino 2 tunnel (2003-2004): restoration of a stretch under the water table following the settlement of the invert (caused by water seepage and simultaneous transport of solid materials into the tunnel due to groundwater level rise).*



7 - *Upgrading to safety standards of the landfills Pariti 1-RSU and Conte di Troia, Manfredonia - Foggia (2010)*
Waterproofing injection treatment of fractured rocks (quarries) where pre-existing landfills were located (waste had been collected inside former calcarenite quarries with no preliminary waterproofing of sidewalls and bottom).

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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