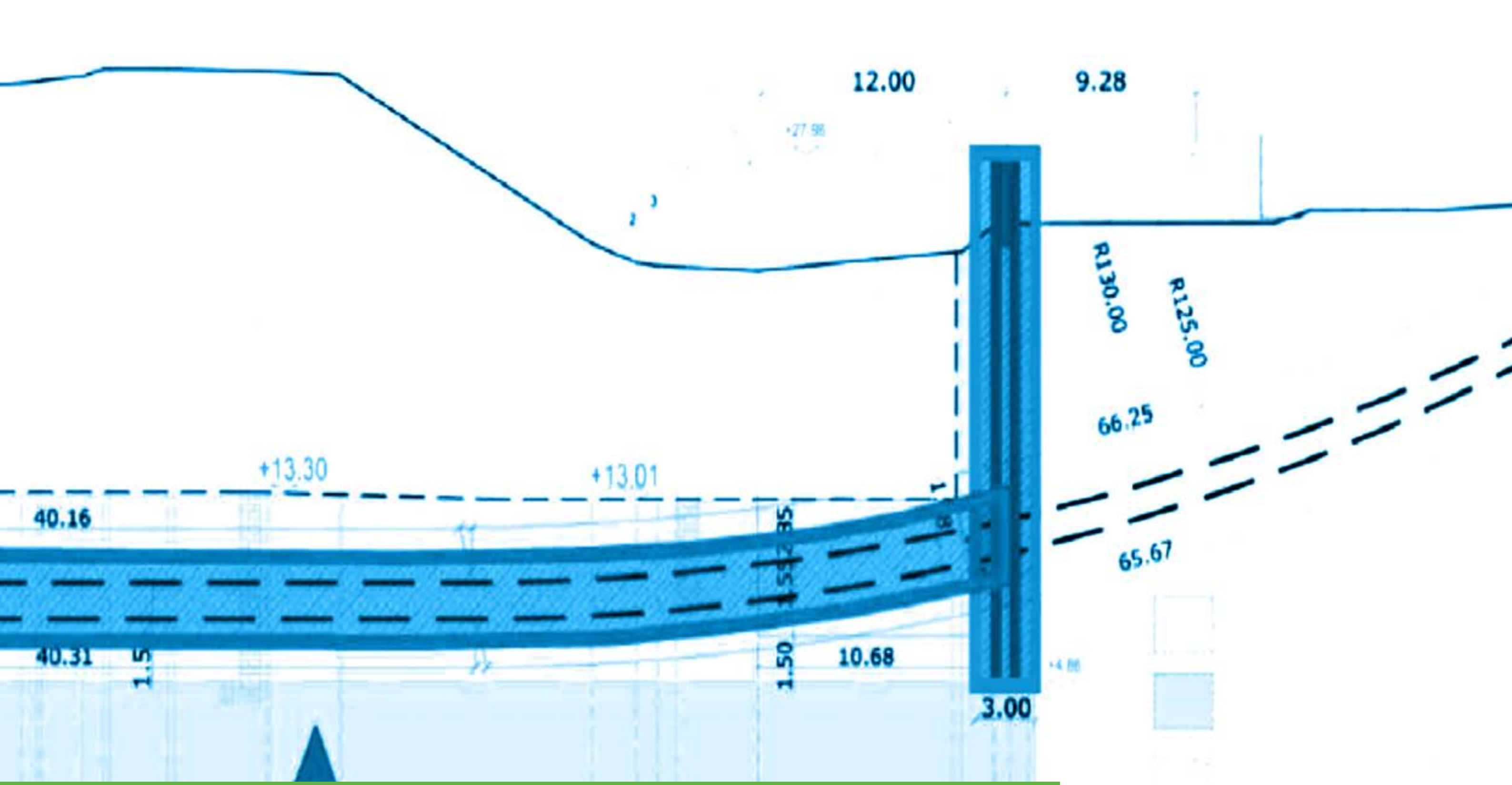


Trevi, a world leader in the field of environmental projects

Environment

TREVI

The Group

Nowadays, Trevi Group is worldwide acknowledged in the field of foundation engineering thanks to the field experience it has acquired, the technology it uses, the constant ability to find timely new and innovative solutions on complex civil engineering needs *(thanks to the never ceasing integration and interchange among the two divisions Trevi and Soilmec)*, and for its predisposition to integrate and collaborate with the local cultures.

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.

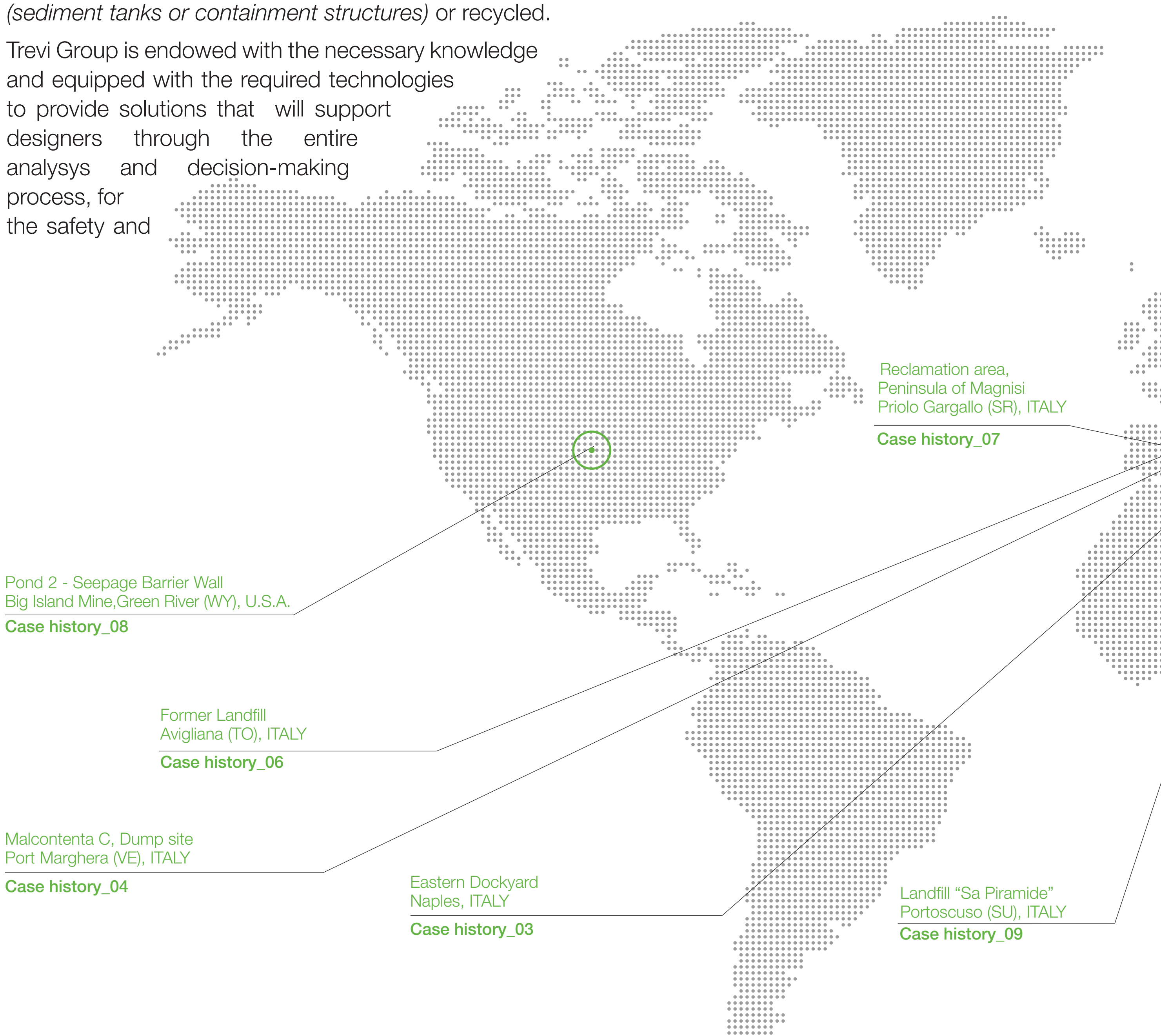
Cover: **Manfredonia - ITALY**
Picture on the right: **Malcontenta - ITALY**

Trevi, green oriented

The protection of the natural heritage is a strategic issue for the proper development of the modern world. TREVI Group has gained considerable experience over the years in the field of contaminated sites remediation and in the isolation of pollution sources from the surrounding environmental compartment. At the same time, it is constantly engaged in the search of new solutions for reclamation and environmental protection, devoting itself to the study, research and application of new methods and technologies.

In fact, innovative systems have been developed **for the removal of contaminants from water and soil** *(SGIBITI - Integrated Geotechnical System for In Situ Remediation of Polluted Soil)*, for the dredging and management of sediments *(Sludge Buster)* to be decontaminated and recycled *(in collaboration with 3V Green Eagle SpA)* and for the stabilization process of the sediments to be trasferred into confined deposits *(sediment tanks or containment structures)* or recycled.

Trevi Group is endowed with the necessary knowledge and equipped with the required technologies to provide solutions that will support designers through the entire analysys and decision-making process, for the safety and

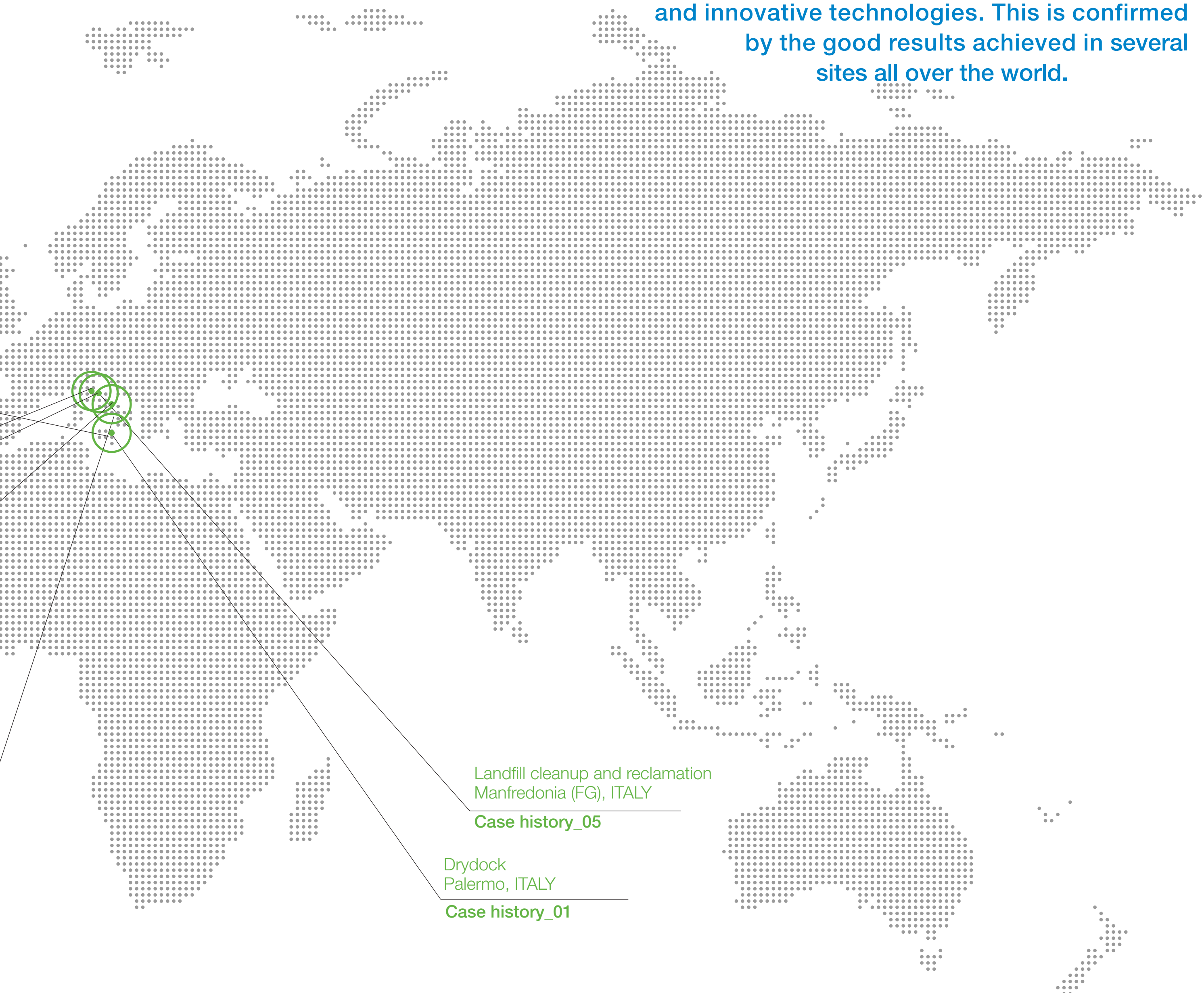


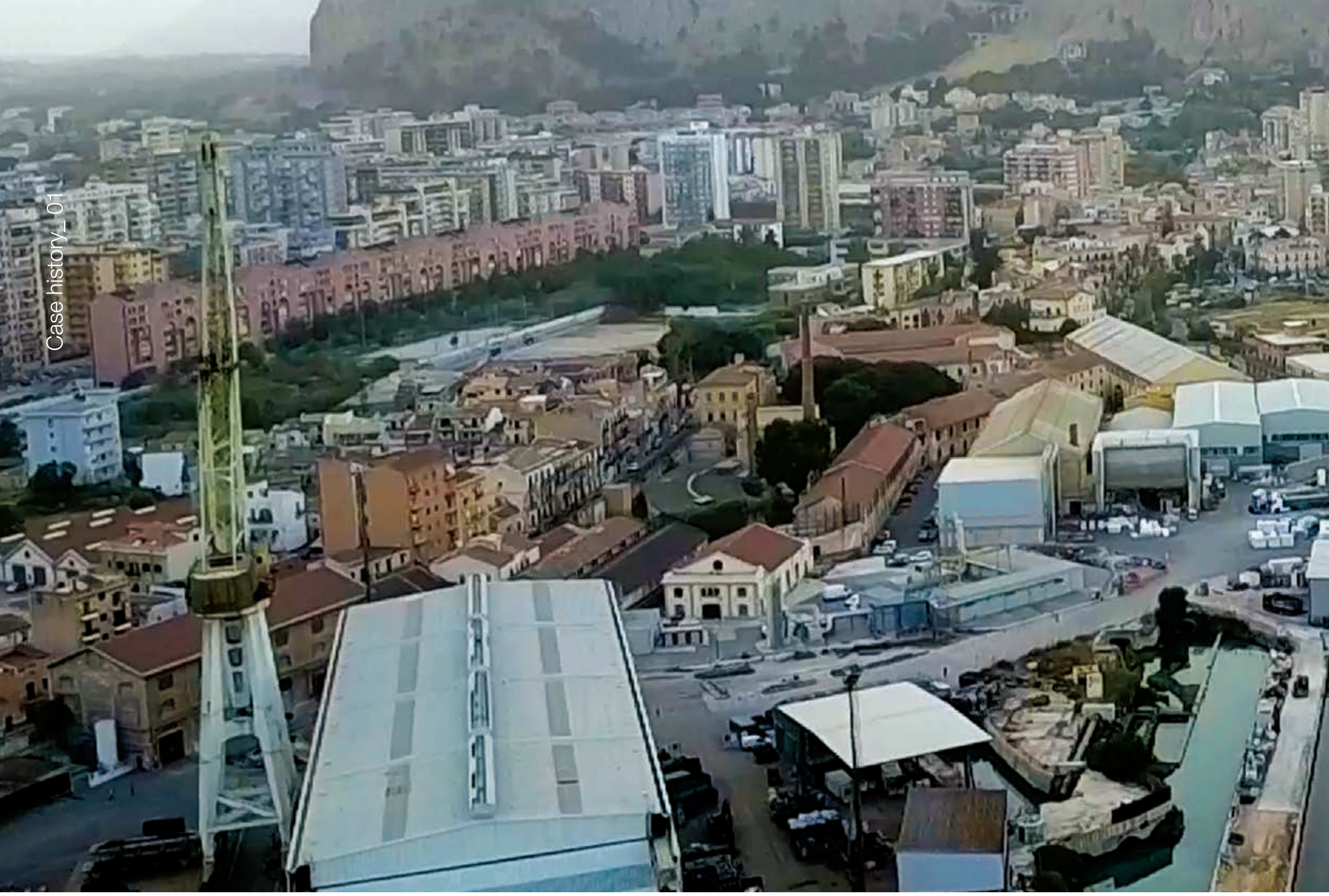
the remediation of contaminated or compromised areas, from an environmental point of view. This is possible by means of the application of proven and innovative technologies for the execution of geognostic surveys, for the sampling of polluted soil and water, for the execution of impermeable or reactive barriers, for the removal and management of contaminated soils and sediment within any type of condition, even in industrial or urban environments.

The technologies used by Trevi Group in the environmental field are many and depend on site-specific characteristics. They include slurry walls with or without HDPE sheeting, secant piles, belts or bottom plugs using high pressure injection column treatments *(Jet Grouting)*, soil mechanical mixing in situ *(DMM - Deep Mixing Method)* or injection of sealing mixtures, which can be also performed following a sub-horizontal guided drilling under the soil volume to be treated *(TDDT - Trevi Directional Drilling Technology)*.

Finally, Trevi has created also the first and largest Permeable Reactive Barrier *(PRB Permeable Reactive Barrier)* in Italy.

It is fair to say that, in the environmental field, Trevi is able to carry out successfully complex works with the application of both well-established and innovative technologies. This is confirmed by the good results achieved in several sites all over the world.





Drydock
Palermo, ITALY

Owner:	Palermo Port Authority
Main Contractor:	Trevi S.p.A.
Work Execution Period:	2014 - 2020

At the end of the 80's Palermo Port Authority started the **construction works for a 150,000 DWT Drydock,** within Palermo Industrial Port. Works were stopped due to a dispute arisen with the Subcontactor.

Up to now the following works - which were included in the original project - have been carried out.

• Construction of the foundation slab after soil remediation with removal and replacement of recent seabed deposits;

• Installation of cellular caissons with the exception of the gate-caisson of the dock;

• Construction of a diaphragm wall along the external perimeter of the caissons to extend the seepage paths during the construction phases untill completion of the foundation slab;

• Final grouting to improve watertightness of the diaphragm wall joints between the single panels;

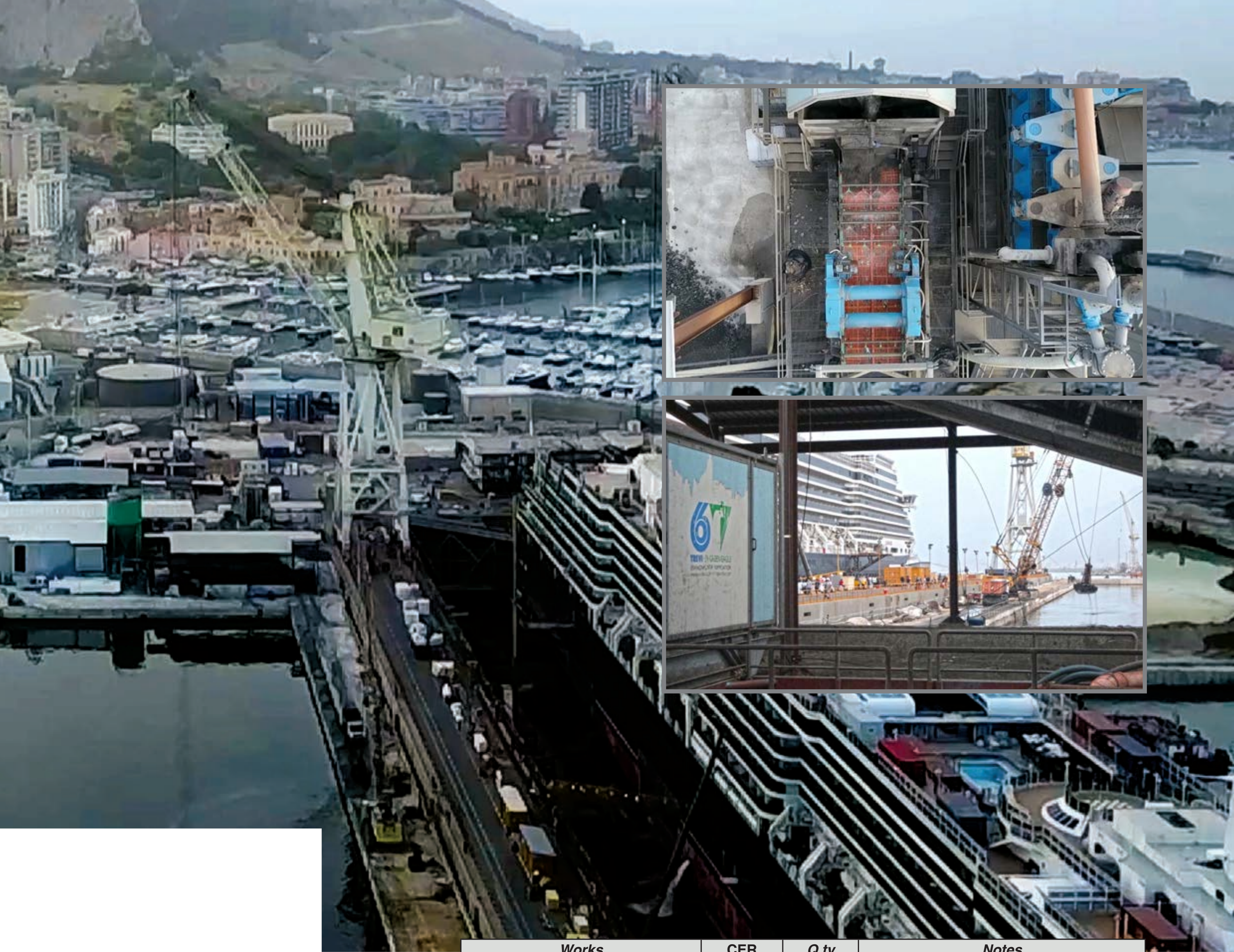
• Installation of the foundation piles under the dock slab, with insertion of tie rods to be stressed later on.

At the beginning of the 2000's Palermo Port Authority, after terminating the Contract, started to plan the completion of the project. In order to assess the progress of work already carried out, it was necessary to perform consolidation and stabilisation works before emptying the dock basin.

Operations specified in the Contract included the **dredging of approximately 76,000 m^3 of sediment and waste, for a total of about 117,000 tons of mainly sandy material**, contaminated by hydrocarbons C>12, heavy metals and mixed waste, most of them conveyed by 2 sewage pipes *(about 500,000 P.E.)* that, until 2014, would discharge next to the Dock.

The objective of the Sediment Washing treatment is the recycling of materials and the consequent reduction of waste to be disposed of. This technology, if properly applied, always reduces the amount of sediment to be recycled/disposed of in external plants so that it can be considered environmentally sustainable and results in compliance with waste management regulations *(In Italy - Art. 179 of D.Lgs. 152/2006).*

The plant recovers material - R5 "Recycling/recovery of other inorganic substances"- from the waste sandy and gravelly fraction of the sediment (Φ > 0.063 mm), according to the specific purposes previously defined.

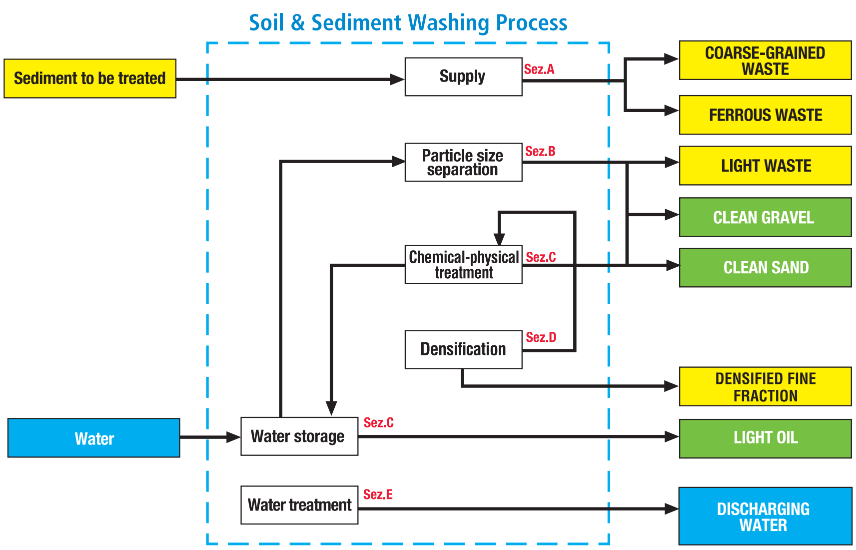


Works	CER	Q.ty	Notes
INPUTS			
Dredging material	17 05 06	111.000 t	
Industrial Water used at the jobsite		14.800 t	*Packaging of reagents and washing*
Recovered sand		41.400 t	*SRW with CE mark as recycled aggregate EN12620, EN13242*
Recovered gravels		15.200 t	*MPS non certificata / Unmarketed SRW*
Filter press panels	19 08 14	25.400 t	
Disposal of other jobsite waste	19 12 12 19 12 09	8.300 t	
Process waters discharged after treatment		12.100 t	*Discharge in Tab 3 D. Lgs 152/06*

After undergoing a compliance audit at the jobsite, the material receives a CE certification as recycled aggregate satisfying the technical requirements according to the specific purposes, regulations and existing standards applied to products.

The separated and densified portion of fine materials and the remaining waste are recycled or disposed of in specifically authorized external plants, while waste slurry is cleaned up in a specific section of the Sediment Washing Plant and is eventually discharged into water *(according to Tab.3 Part 3, Attachment 5 of D.Lgs. 152/2006).*

Once the works had been finished, approximately 111,000 tons of waste were treated, recovering 41,400 tons of sand, 15,200 tons of gravel, while 25,400 tons of contaminated fine fraction were disposed of in an external plant.



Eastern Dockyard
Naples, ITALY

Owner:	Naples Port Authority
Main Contractor:	Trevi - C.C.C. JV
Work Execution Period:	2011 - 2017

The containment area bordered the dock shoreline on three sides. The intervention along the upstream one, located to the north, had already been carried out urgently as it was linked to the safety of the aquifer.

The other two sides were located to the west and to the east: the first one along the quay of “Progresso” dock while the other one on the border with the power plant.

These boundaries were protected using the Cased Secant Piles technique *(CSP)*, which allowed to realise a plastic diaphragm wall, obtained without mixing the soil in situ. **The CSP was selected because more effective than other techniques in overcoming the difficulties caused by the soil and in crossing very hard elements such as concrete blocks and rocks *(part of breakwaters and rip-rap protections)* present within the dockyard confined disposal facility.**

The diaphragm wall was made of bored piles with a diameter of 1.0 m and a c/c distance of 0.70 m; they were installed alternately, i.e. proceeding with primary piles at a c/c distance of 1.4 m and subsequently intersected by secondary closing piles, which overlapped the primary piles by 0.30 m, with their partial drilling.

The result was a continuous, waterproof diaphragm wall, regardless of the excavation geometry, with a minimum thickness of 0.70 m.

The piles were installed at an average depth of 24-25 metres *(the deepest ones reached 28 m)* so that they would result well embedded inside the tuffaceous layer.

For the drilling, a Soilmec SR-100, class 100 tons, equipped with a 28 m mast and set up in CSP version, was used.

The selected concrete type was specifically batched to ensure a very low permeability coefficient.

Tests carried out on site showed that the final permeability coefficient were up to two orders of magnitude smaller than the one required in the design *(up to 1 x 10-11 m/sec, i.e. ten or one hundred times smaller than the minimum design requirements)*, therefore assuring a performance level able to guarantee the safety margin always necessary for works of this importance.

Diaphragm walls CSP:	**17.000 m^2**
CSP Piles:	**n. 950**

Malcontenta C, Dump site
Port Marghera (VE), ITALY

Owner:	Syndial SpA
Main Contractor:	Trevi S.p.A.
Work Execution Period:	2016 - 2018

The project to secure the "Malcontenta C" area concerns a contaminated site north of the town of Malcontenta (VE) where various industrial activities were established between the 1960's and the 1980's. These areas were used as sites for transferring raw materials and industrial process waste coming mainly from the production-sites of Port Marghera industrial complex.

The area was about 10 hectares. **The interventions on the areas mainly consisted of an encapsulation of the ground by means of the construction of self-hardening slurry walls and a surface capping**, as well as the realisation of a system of hydraulic barriers with the aim of confining the aquifer inside the area, so that its level would be kept below the level of the external aquifer.

The main activities can be summarised as follows:

• Construction of internal drainage trenches for the control and interception of seepage water within the soil filling;

• Installation of vertical drains limited to the depth of the first aquifer;

• Creation of a plastic composite self-hardening slurry wall along the perimeter by means of a ternary mixture made of water/cement/bentonite and with a HDPE sheet inside for the entire depth of the wall;

• Creation of a multilayer waterproof cap to protect the soil surface *(capping)*;

• Top soil covering, with appropriate sloping and final grassing and construction of special service tracks;

• Installation of piezometers;

• System for collecting, regulating and diverting surface and run-off rainwater.

Due to the interference with high voltage power lines that could not be dismantled before the commencement of the work, a part of the works for the perimeter belt was carried out using special technologies and adopting suitable equipment to maintain an adequate distance from the power lines. In particular, a portion of the barrier was realised by means of CSP secant piles made of plastic concrete, with the same hydraulic characteristics as the slurry wall.

Diaphragm walls (HDPE):	16.000 m^2
CSP Piles:	1.200 m
Jet grouting:	2.000 m
Draining trenchers:	10.000 m^3

Landfill cleanup and reclamation
Manfredonia (FG), ITALY

Owner:	Delegated Commissioner Office for the Remediation of Public Dumpsites
Main Contractor:	Coop. Mucafer - CCC. JV
Work Execution Period:	2010 - 2011

Trevi S.p.A., the underground engineering division of Trevi Group, worked in Manfredonia with innovative techniques to permanently reclaim two contaminated sites used as landfills for municipal solid waste.

The “Pariti 1-RSU” and “Conte di Troia” landfills had fell into disuse for decades; they were located in the town of Manfredonia, within the Province of Foggia, about 6 km south-west of the town centre.

The sites were actually two abandoned calcarenite mines *(soft, yellowish, tuffaceous limestone)* located at different elevations, on the right and left banks of a small gorge named Vallone di Mezzanotte. **The two landfills were about 25,000 m each; the total volume of discharged waste was 400,000 m^3 with a maximum thickness ranging from 16 m *(Conte di Troia)* to 25 m *(Pariti 1)*.**

In subsequent years the landfill was abandoned, ground water analyses were carried out in the area of the town of Manfredonia and significant traces of leachate percolation were found. After a series of legal actions and the initiation of an infringement procedure by the EU, in November 2008, the Court of Justice issued a sentence condemning the failure to complete the clean-up of the two sites with severe sanctions.
Such decision was suspended as the Italian Government committed to reclaiming the sites by 2010.

A long and complex bureaucratic procedure followed and resulted in the declaration of a state of emergency in May 2009.
At that time a Commissioner of Reclamation and an Enforcement Subject were appointed so that, in the first months of 2010, the works for the permanent clean-up of the areas were started.

The first project hypothesis was based on the idea of removing completely the waste and transferring it to another landfill, or alternatively, stocking it temporarily at another site and taking it back to the original site after clean-up.

However, the abovementioned hypothesis was rejected for reasons of cost, time and environmental impact. In order to create an effective on-site barrier without transferring the waste off-site, the project *(developed by Sviluppo*

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

Italia Aree Produttive with geotechnical advice being provided by Studio Sintesi) identified a method of intervention aimed at considerably reducing secondary permeability *(due to fissures)* and primary permeability *(where dissolved calcarenite was locally present)*.

The major technical challenge was the creation of a bottom plug for the landfill. Since the formation of a waterproof screen by material replacement was not technically feasible, it was decided to make substantially impermeable the layer underlying the waste. Fissures, discontinuities and gaps responsible for its high permeability were filled up by injecting cement and silicate grouts. A final permeability of 5 LU *(Lugeon Unit)* was taken into account.

The screen was specifically designed to adapt to the landfill bottom surface and to ensure continuity with the perimetral barrier. A rocky layer of 3.0 m thickness was treated at variable depths, around 2.5-3 m below the waste level.

The creation of the screen through the application of traditional techniques would have required thousands of vertical drillings in order to penetrate the waste and reach the underlying rock layers to be injected.
This solution was therefore considered too expensive, time-consuming and environmentally risky.

As a result, an innovative solution was proposed, inspired by the recent introduction in the geo-engineering sector of the Horizontal Directional Drilling *(HDD)* techniques, which were widely used in the oil industry and for the installation of utilities *(named No-dig technologies)*.

Adequately modified and integrated, the abovementioned technique *(renamed **TDDT: Trevi Directional Drilling Technology**)* enabled sub-horizontal curvilinear drillings of remarkable length *(in this case up to 180 m).*

In this specific case, the horizontal directional drillings were started from one of the landfill sides and reached the other one, intersecting both the vertical perimetral barrier and passing below the landfill for the whole length.

According to project specifications, a drilling accuracy of 30 cm was to be achieved.
Steel sleeves supporting the pipes were placed inside the boreholes for cement and silicate mix grouting.

Former Landfill
Avigliana (TO), ITALY

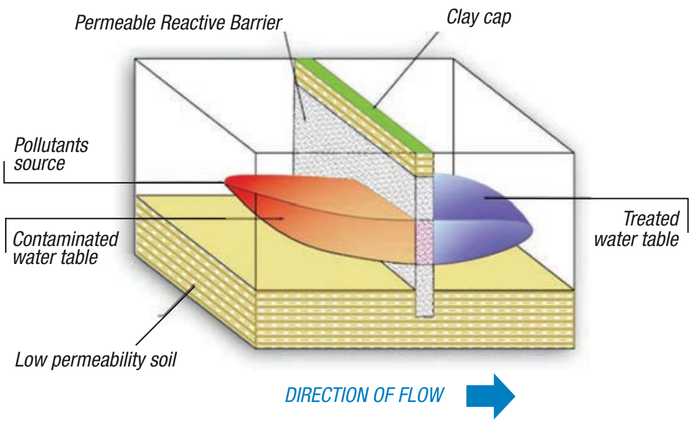
Owner:	TEKSID SpA
Main Contractor:	EDIL MA.VI. Torino Srl
Work Execution Period:	2004

The landfill, authorized in 1991 as a disposal area for molten iron slag, is located in the Dora Riparia Valley, about 10 km west of Turin.

Water monitoring tests carried out by ARPA *(Regional Environmental Protection Agency)* on August 1999 detected **the contamination of the shallow groundwater, caused by the presence of chlorinated solvents, and specifically of trichloroethylene.**

The contamination was probably originated by drums abandoned at the end of the 80's inside a ground trough, within the disposal area, a few meters from the riverbed. The drums were probably damaged, during the preliminary earthmoving works for the disposal of the molten iron slag.

A 600 mm thick permeable reactive barrier, made up of zerovalent iron, was installed between the landfill and the river, following an alignment parallel to the riverbed, a few meters from the bank. **The total area of the barrier was 1,560 m^2, with a linear extension of 120 m and an average depth of 13 m.**



The trench was excavated within a sandy-gravelly soil turning sandy-silty going deeper, and was embedded 1.0 m into the bottom clay layer.

1,700 tons of zerovalent iron were cast into the trench; the iron was composed of grain-sized particles, measuring 0.2 ÷ 3 mm, and was utterly free from oil or other impurities.

Inside the barrier, five piezometers were installed, to monitor the chemical and physical groundwater parameters and to evaluate the evolution of the barrier performance in time.

Reclamation area, Peninsula of Magnisi
Priolo Gargallo (SR), ITALY

Owner:	Sviluppo Italia Aree Produttive SpA
Main Contractor:	TREVI - TESECO JV
Work Execution Period:	2006 - 2011

The Site of National Interest *(SNI)* of Priolo Gargallo was established by Law 426/1998 and stretches along the south-eastern coast of Sicily for about 30 km, including some areas of the municipalities of Augusta, Priolo Gargallo, Melilli and Syracuse.The plants present in the industrial area were chemical and petrochemical, but there were also cement factories and asbestos treatment plants, hazardous waste incinerators, etc.

Over the years, hazardous substances and materials had mainly contaminated the soil, but also the coastal plains. In 2004 a framework agreement was signed for the remediation of contaminated areas in the SNI of Priolo Gargallo. **The project to make the coastline environmentally safe in that emergency situation was awarded to Trevi, and envisaged the execution of excavations for the "removal of materials consisting of pyrite ashes and contaminated landfill waste", in order to restore the original coastline.**

The technical specifications for the execution of the excavations required "confinement of underground waste by physical barriers, to minimise the infiltration of seawater and to avoid external dispersion of the contaminants to be removed".

For this purpose, a provisional **secant piles wall, made of plastic concrete, 15 m deep and formed by piles with ø 900 mm and c/c distance 600 mm, was installed by means of the CSP technology** *(drilling with continuous auger and casing, and concrete casting by the same drilling tool)*. The only purpose of this diaphragm wall was to close the most permeable layers on the lateral sides, blocking their horizontal permeability, and to lengthen the flow lines in order to reduce water seepage from the bottom: groundwater entering the confined area through the bottom should be protected by a network of well points connected to a disposal system.

To allow the complete removal of ashes and contaminated soil, the secant piles wall was installed on a new berm, specially made for this purpose.

The axis of the secant piles wall along the seaside berm was connected with the portion of the wall that, on the mainland side, ran parallel to the original natural coastline.

As required by the technical specifications, after the completion of the excavation operations intended to remove the waste, the berm and the existing reef were dismantled and the original coastline was restored.

Pond 2 - Seepage Barrier Wall

Big Island Mine,Green River (WY), U.S.A.

Owner:	OCI Wyoming, L.p.
Main Contractor:	TREVIICOS South, Inc.
Work Execution Period:	2014

The seepage barrier wall was installed through layers of silty sand, clay, gravel, siltstone and sandstone using a combination of clamshell bucket and hydromill trench cutter for the excavation activities.

The self-hardening slurry method was used to form the barrier wall, while the excavations operations were carried out by two different techniques: with a mechanical clamshell through the embankment, and with a hydromill trench cutter through the siltstone and sandstone layers, up to a depth of 65 ft. from the working platform.

A unique feature of the project was the installation of a test panel outside the alignment with a large amount of testing which included coring, wall surface inspection, joint verification and monitoring of wall homogeneity during destruction.

This additional information, from execution records and quality control procedures, provided a baseline for the compliance monitoring activities carried out during the construction phase.

Acceptance testing of the seepage barrier wall was performed after 28 days through UCS and Permeability testing of cast in-situ samples. Samples were taken during each work shift to monitor the situation.

Acceptance criteria to be achieved during testing included:

- **Permeability < 1x10^{-8} m/sec @ 28 Days**
- **Strength > 520 kPa @ 28 Days**

To ensure compliance with the stringent requirements of the design, real-time tests were carried out, throughout the entire installation of the barrier, at the batching plant. Additional tests were carried out during excavation, including verification of panels position, depth and verticality.
The project was completed ahead of schedule, respecting very high standards of quality control and safety and with full Client's satisfaction .

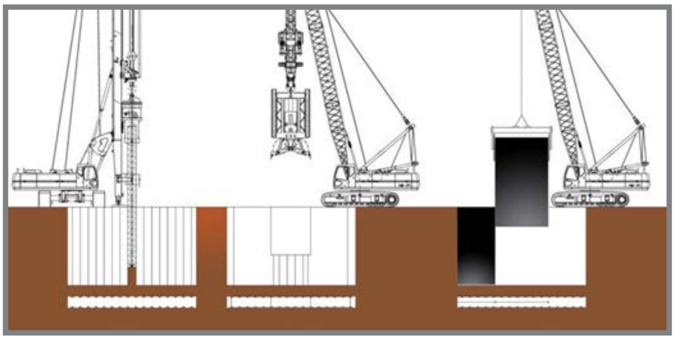
Landfill “Sa Piramide”
Portoscuso (SU), ITALY

Owner:	Syndial
Main Contractor:	Locci Brothers Ltd.
Work Execution Period:	2007 - 2008

The landfill, which had collected slag from the metallurgical processing of lead and zinc minerals, was decommissioned in 1992 and had already been subject to recovery measures in the past. Further characterisation activities led to the drafting of a new project for the remediation of the area.
The site to be permanently secured covered an area of approximately 32 hectares divided into four homogeneous sub-areas depending to the different types of actions they required. The safety measures in the Western Area required the construction of a diaphragm wall to segregate the land and any leaching water from the landfill, over a linear extension of approximately 340 m. **The required diaphragm wall was a composite self-hardening slurry wall *(thickness 0.8 m)* which included also an HDPE geomembrane, created by the installation of separate sheets that were made continuous by means of joints.**

Due to the particular geology of the site, it was essential to remove or crack the rock layer to allow the construction of the continuous diaphragm wall.

This cracking was attained by drilling secant holes, made with the CSP technology *(drilling with auger and casing)*, with Ø 900 mm and c/c distance of 600 mm, which allowed the almost complete removal of the rock along the axis of the diaphragm wall.



The diaphragm wall was divided into six segments, each segment being installed after the other and working on platforms created at different elevations. The continuity of the diaphragm wall was achieved by creating joints between the segments and by overlapping the HDPE geomembrane.

At both ends, the diaphragm wall was connected to a shallow composite diaphragm wall, directly embedded into the rock formation using a roadheader.

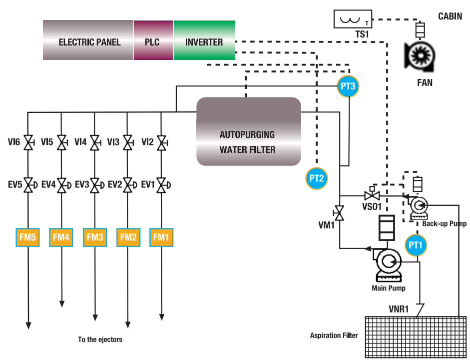
Research and development activities related to innovative management of sediments deposited inside bodies of water

The problems related to sediment management strongly affect the development of many harbour areas, cause serious concerns about the hydraulic safety of rivers and streams and can reduce the storage capacity of artificial reservoirs. Sustainable management of these materials aims to minimise the use of natural resources and the impact on potential receptors throughout the management cycle. Hence, there is a need to maximise, where possible, the material recycling as a resource for industrial activities or morphological/environmental restoration.
The nature of the sediments, the different contaminations, the removal techniques and the possibilities of decontamination, recovery and/or replenishment involve different technical and scientific disciplines. Based on these assumptions, Trevi Group has developed and applies innovative sediment management technologies, which can be modulated according to specific needs and are applicable to the entire management process.

Marina Plan Plus: the technology to keep the seabed elevation stable and to maintain hydraulic works.

Trevi Spa, acted as coordinator of a research group that included the University of Bologna, the Municipality of Cervia and ICOMIA *(International Council of Marine Industry Association).* The Group in 2016 obtained from the European Commission funding of about 1.5 million Euros for a research project entitled **"Marina Plan: reliable and innovative technology for the realisation of a sustainable marine and coastal seabed management plan"**.

The funding led to the implementation the first industrial-scale application of innovative and sustainable technology for the management of the seabed elevation at the entrance to the port of Cervia. The technology could revolutionise the way hydraulic infrastructures are managed by making dredging maintenance operations infrequent or unnecessary.



5 ejectors pumping plant - P&I

The equipment avoids the sedimentation of solids at the point of application by installing submerged elements - the "ejectors" - resting on and fixed to the bottom. These elements, suitably flushed with water under pressure, can aspirate the solid/liquid mixture present in the surroundings and move it away, using piping, in an area where it will not be an obstacle for navigation, hence keeping stable the seabed elevation or keeping clear the hydraulic work they are intended to protect *(dock foot, valve or mobile bulkhead, etc.)*.

The plant has been designed to produce a solid/liquid mixture, normally between 1-5%, thus obtaining a very low concentration of solid material. As a result, there is no turbidity or re-suspension due to plant activity either near the ejectors or near the outlet point of the exhaust pipes. The outlet points of the system exhaust pipes are positioned in favour of current to allow natural sediment removal.

The ejectors are designed to move the sediments, naturally carried by the sea currents, from a place where their presence causes a reduction of the water depth, to another place where the sediments themselves either will be transported away by the currents or will not represent an obstacle to navigation.

The plant operates with a zero mass balance since the sediments transported by the sea currents are those that the plant moves away from the entrance to the port. The plant, therefore, does not carry out any dredging and falls within

Portoverde filtration system

the scope of the exclusions referred to in Decree 173/16.

LIFE funding has also the execution of the LCA *(Life Cycle Assessment)* for this technology, with encouraging results. The envision certification process, an independent certification assessing the real sustainability of infrastructure design, is currently ongoing.

Screening of the sandy fraction of the dredged sediment and stabilisation of the fine fraction.

In case it is necessary/convenient to screen the sandy fraction of the sediment, a complete process of **Sediment Washing** can be adopted to achieve particles size separation, simultaneous reduction of possible contamination of the sandy fraction and compaction of the fine fraction.

The first phase increases the efficiency of the entire management process with the optimisation of management costs. In fact, by means of the particles size separation, the physical characteristics of each fraction the material will be made homogenous and the maximum reduction of the volumes to be disposed will be achieved.
Once the sand has been separated, the suspension containing the fine fraction of the sediment is managed. In case of recycling the fine fraction of the sediment as a foundation layers of port infrastructure, a centrifuge densification process will be applied and binders will be mixed with such fraction.

This process combines compaction and stabilisation of the fine fraction for recycling or disposal.

The binder mixture is designed to minimise the water quantity to be added during the process and is inserted directly when the material enters the centrifuge, so that the binder particles are perfectly mixed with the solid matrix.

The results is a material that immediately starts hardening.

The centrifuge allows automatic control of the quantity of mixture to be added, based on the flow rate and density characteristics of the incoming silt and clay suspension.
The final quantity of binders per ton of dry solids, present inside the compacted material, shall be calculated based on the required characteristics and its purpose.

The laboratory tests carried out by the Marche Polytechnic University on samples taken during the tests, allowed to verify the unconfined compressive strength and shear modulus of the treated materials. These values were consistent with those ones required for subgrade layers of road and port infrastructures.
Moreover, the samples showed an extremely low permeability, similar to what is required for the barriers of confined disposal facility.

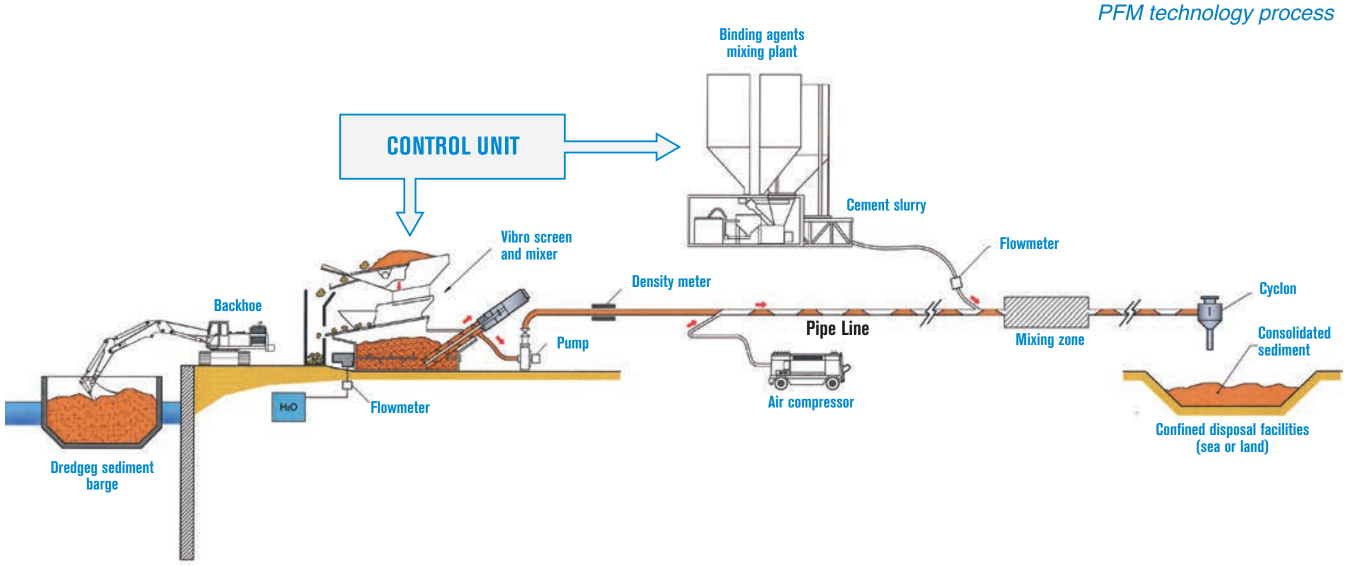
Stabilisation of the entire mass of sediments in case of confined disposal facility replenishment.

If the separation of the sandy fraction from the entire sediment mass is not necessary or convenient, a technology called **"Pneumatic Flow Mixing"** *(PFM)* can be applied.
The technology combines in a single process the different phases of the dredged material management *(transport, stabilisation and replenishment operations)* with considerable reduction in terms of cost and execution time, ensuring a considerable homogeneity of the stabilised material.

In case the final platforms of confined disposal facilities should be used as port infrastructures, substantial mechanical characteristics may be often required for the shallow sediment layers.

The stabilisation of the material can be carried out before the transfer, at the same time or after the replenishment operations. In the latter case, punctual techniques are generally used, with treatments performed with cutting tools

PFM technology process



rotating around either the horizontal or vertical axis. Such a technique, called deep mixing, has obvious limitations like complexity of the treatment, logistic difficulties, impossibility to stabilise the whole mass and longer execution time. Quite the opposite, in case of stabilisation before or contemporary with the replenishment operations, the whole volume is treated homogeneously before pouring the filling, and the final platforms will be available in a short time. Stabilisation technologies are usually used for this purpose by means of specific mixing plants *(such as pug mill or others)*.

The process starts with the transportation of the dredged sediment to the plant where it will be mixed with the binding agents, then the treated material will be transported by trucks or other means to the operations area and finally the replenishment will be completed.
As an alternative to this costly method, the **"Pneumatic Flow Mixing"** *(PFM)* could be considered. The PFM method is an innovative process whose main and distinctive features lie in the pneumatic transportation of the dredged sediment and the in-line injection of the stabilisation agents, before or during transportation.

Depending on the specifications, the particular required performance can be achieved by adjusting the water/binder ratio. The stabilised material obtained through this process can be used as a sub-foundation of new port yards for instance. The platform of the yards can be completed laying down the road pavement layers a few days after complete curing of the mixed material.

In order to test this potentially revolutionary technology, Trevi S.p.A. was awarded a specific contract in 2013 by Sogesid, an engineering company belonging to the Ministry for Environment, Land and Sea Protection. The purpose of this contract was to verify the applicability of this technology to the stabilisation of about 20 m^3 of sediment extracted from the ports of Livorno and La Spezia.

In collaboration with the Department of Industrial Engineering DIN of the University of Bologna, the preliminary design of a pilot plant was developed, based on works carried out by several authors who had been sstudying this topic for long time. the design was then improved, and the plant was built and used for the stabilisation and replenishment tests in the pilot confined disposal facility.
Several tests were carried out, and several samples were taken and then subjected to both permeability and mechanical resistance tests. The results demostrated that the material from both port areas, before being stabilised, was already compliant with the specifications for replenishment of confined disposal facilities and could be used for reclaiming the areas of new port yards.
Port yards could be completed adding a final shallow layer of filling and the road pavement layers, 60 days after the material curing process. By increasing the quantity of binders used for the stabilisation process, it was also possible to achieve the required stiffness characteristics for the sub-base layer of the pavement.

Sediment as material for the construction of low permeability diaphragm walls

Many hydraulic works, such as river banks or earth dams, require low permeability diaphragm wall. Similarly, diaphragm walls of this type are used as barrier for contaminated sites or confined disposal facilities.

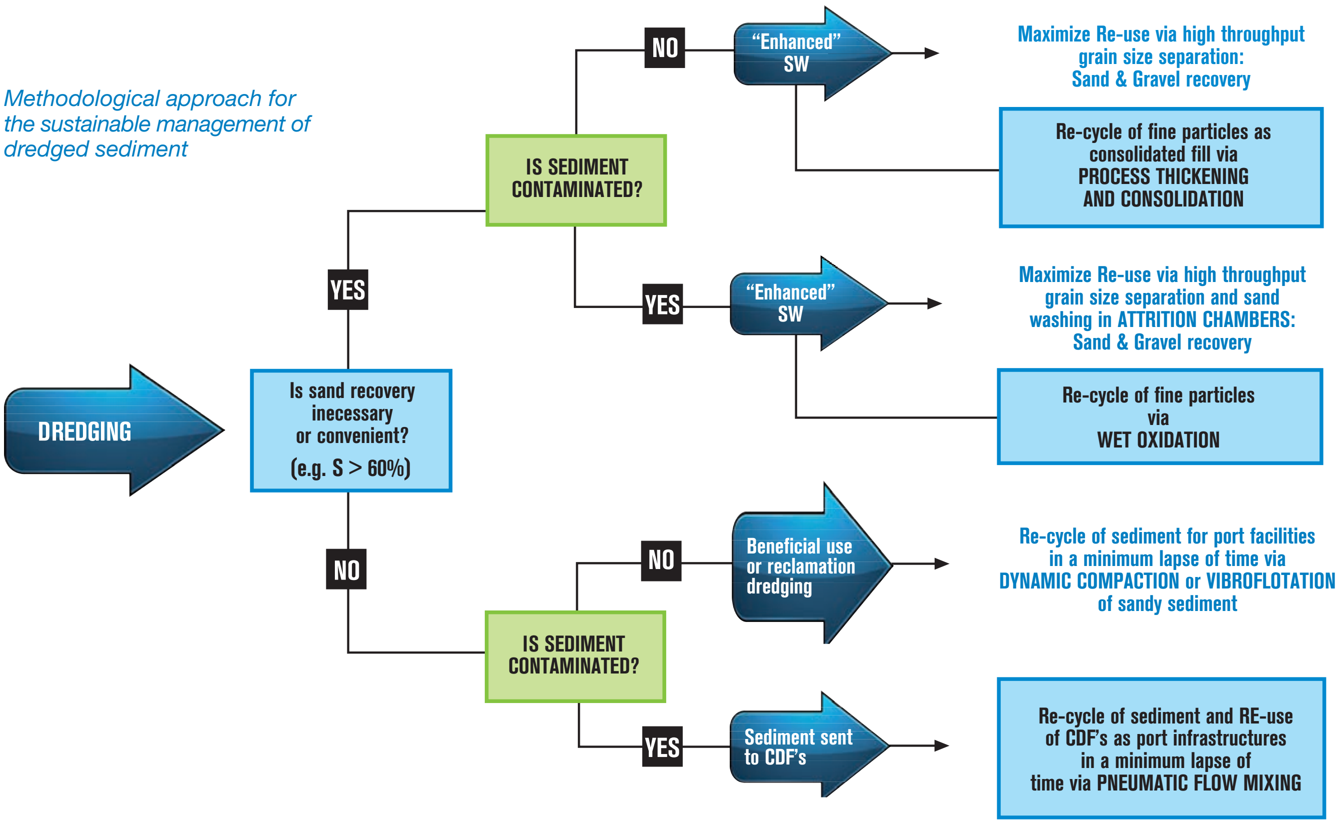
After separation of the dredged sediment fractions, based on their grain size, and after treatment, the opportunity of recycling specific fractions in a low permeability plastic mix for the creation of barriers was evaluated, with the scope of ensuring a hydraulic and mechanical performance meeting the designers' typical requirements.

In collaboration with the SMAU Department of the Marche Polytechnic University, a research was carried out on sediment from the port of Livorno, which were used for the design of various ternary mixtures with cement and bentonite, as well as with the addition of different types of commercial designated mixes.

Different types of mixture were prepared and while a part of the samples was cured in fresh water, the other part of the samples was cured in sea water, to verify the possible influence of salinity on the mechanical and hydraulic properties. All the samples were subjected to compressive strength and long-term hydraulic conductivity tests after a curing lasting up to 300 days.

The abovementioned research, followed by several papers, supports the statement that sediment is a valuable resource able to replace quarry aggregates for the design of mixes to be used for the construction of low permeability diaphragm walls, with consequent sparing in the use of natural resources.

Methodological approach for the sustainable management of dredged sediment



Case histories in nuclear waste sites

Over the years, Trevi S.p.A. has been demonstrating the competence to improve and the ability to master various technologies that have been recognised as crucial by Italian Public Authorities for investigating or securing **specific sites where nuclear waste is stored or has previously been stored.**

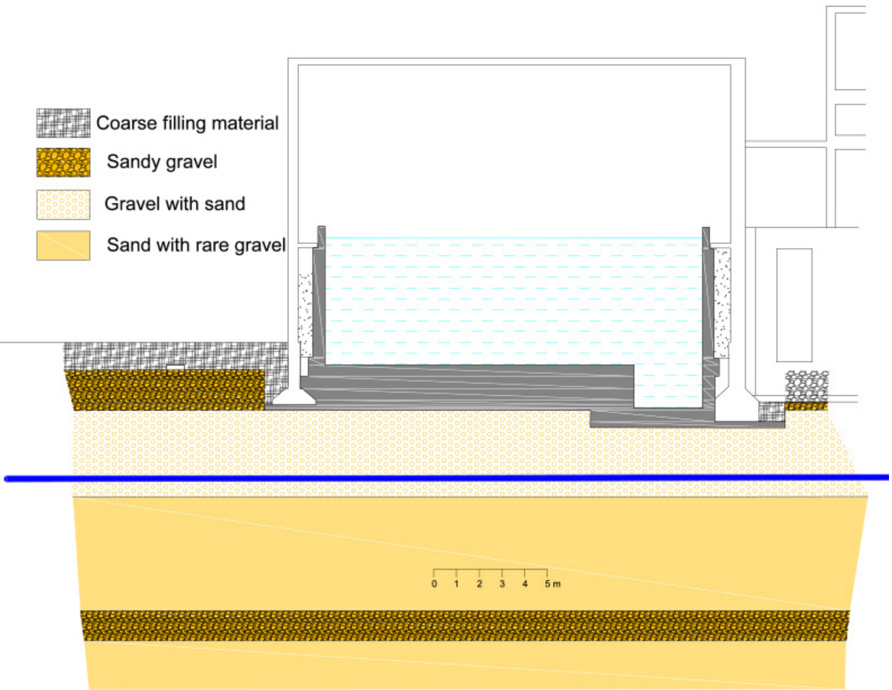
In particular, two case histories will summarise the possible applications of these technologies in such situations.

EUREX Plant in Saluggia (TO), Italy

The Saluggia plant was built in the 1960's and operated until the early 1980's for the reprocessing of nuclear fuel *(MTR and CANDU fuel)*. It is part of the Saluggia nuclear district, which also includes facilities called Avogadro *(off fuel storage facility)* and Sorin *(materials for the biomedical industry + nuclear waste storage facility)*.

The largest drinking water well in the region, which supplies more than 100,000 people with potable water, is located 1.5 km downstream of the district.

An extensive monitoring campaign was undertaken at the Eurex plant since 2004, when contaminants were identified in water samples collected in the area surrounding the "switched off" fuel collection tank.



Particular attention was paid to monitoring activities since 2006, when **abnormal concentrations of Sr-90** were found in groundwater samples taken at shallow depths (0.02 bq/l ≈ 0.5 pci/l). As a result, the monitoring network was progressively extended, and to date, more than 40 monitoring wells are available within the facility *(more than 100 within the safe area)*.

In June 2008, the "decommissioning" of the spent fuel pool was completed *(fuel removed and transferred, drain and tank cleaned)*. Monitoring activities showed abnormal values in Sr-90 concentrations, whose persistence varied with the groundwater level *(monthly analyses; max. conc. 0.88 bq/l ≈ 23.7 pci/l)*.

To investigate the residual soil contamination under the tank foundations, a series of directional sub-horizontal drillings, awarded by Sogin in 2009 to RCT-Trevi, were planned.

As part of the precise requirements for the work activities and under strict control to avoid radionuclide contamination, four sub-horizontal drillings were carried out to collect samples in the foundation soil below and above the groundwater level.

The drillings were directed by installing two lines equipped with several electrodes at the ground level in order to create an artificial magnetic field useful to act as a reference for guiding the drillings.

Another magnetic field was induced by an electrical conductor placed underground inside the first drillhole.

The **"Paratrack"** probe and special drilling tools allowed to reach the exact soil volume to be investigated with an accuracy of 1 cm, even though drilling operations were difficult because of the gravelly soil.

77 samples were tested for radiological protection *(gamma spectrometry with mda=3÷10 bq/kg).*

19 samples were selected for full radiological analysis *(gamma, Sr-90, alpha).*

2 additional samples were taken from a hole located outside the plant footprint in order to set a zero reference value.

8 samples were taken away by the control authority.

The investigation allowed to reconstruct the extent and degree of soil contamination, as well as the possible position of the leakage point, and resulted in the evaluation of a further plan of actions.

Enea Research Centre in Rotondella (MT), Italy

The work inside the Enea research centre in the municipality of Rotondella (Matera), Trisaia, was carried out on behalf of Sogin S.p.A.

This company managed at a national level the storage sites for radioactive materials and for any other material related to them.

In the specific case, Sogin provided for the creation of a barrier to enclose a specific area containing a monolithic structure where radioactive materials were stored. **The containment of this area, carried out while the plant was fully operational, was motivated by the aim of minimising water infiltration and avoiding dispersion to the external environment.**

Soil investigations had shown a stratigraphy formed by sandy and gravelly soil layers that were quite permeable; only the deeper formation showed low permeability, being composed of stiff clay.

The barrier was created through the installation of 80 secant pipes *(CSP technology)* to form a wall. The piles were divided into primary and secondary elements, with a nominal diameter of 920 mm, with a c/c distance of 60 cm and with a maximum depth of about 16 metres, up to the deep clayey formation.

The CSP technology was chosen because it is based on a dry excavation concept, i.e. without the use of slurry.

This feature is highly appreciated in projects in urban areas and particular situations as waste disposal problems are reduced and very small plant areas are necessary.

The reduced space within the site to accommodate and handle the equipment meant that the utmost care should be taken in handling and logistic operations; besides, the operating specifications imposed a series of preparatory phases, sequences and precautions in the execution phase such as drilling with a sequence that would not cause vibrations, extraction of tools by steps in order to ensure a precise inspection of the soil, maximum accuracy in the concrete casting phase.

The spoil material underwent the first check and then was loaded directly onto trucks and stored inside specific areas where it could have been prepared for further analysis and control.

Technologies special application
for environmental sector

SHEET PILING

Sheet piling technology is commonly used in many engineering fields. It is an advantageous solution for excavation supporting, protection of side walls and in marine works, just to mention a few of its numberless applications.

DIAPHRAGM WALLS

Diaphragm walls are built underground starting from the surface. Their use has evolved from the old practice dating to the beginning of last century and consisting in adding bentonite to drilling fluids in order to stabilize uncased boreholes.

They are constructed by digging a trench, filling it with bentonite mud, then placing a reinforcement *(steel cages, soldier piles, etc.)*. At the end, the slurry is displaced by means of the subsequent concrete placement casting using the tremie method.
They can be built can be built with zero clearance to existing structures, act as underpinning of superficial foundations and, in conjunction with pre-founded columns, constitute the perimeter wall in top-down construction schemes.

Slurry walls are very versatile: they can assume any shape in plan, have thicknesses varying from two to five feet and can reach depths in excess of 400 feet through every imaginable soil condition.

Circular slurry walls permit unbraced excavation while post-tensioned slurry walls allow for greater unsupported spans.

HYDROMILL

Diaphragm walls are common practice in civil engineering as part of/or support to the construction 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. The walls having a hydraulic function can be sub-classified into impervious (cut-off) and draining walls.

PLASTIC CUT-OFF WALLS

They are used to install impervious barriers and are generally made up of a mixture consisting of either bentonite-cement, soil-cement-bentonite or plastic concrete with or without a HDPE liner inside.

JET GROUTING

By means of the TREVIJET system it is possible to obtain columns with the various diameters and geometry *(pseudo-elliptical jet).* Dimensions and mechanical features of the treated soil mostly depend on the combination of several elements, such as soil type, jetting parameters and composition of the grouting mixture.

TURBOJET

With the TREVIMIX-TURBOJET technique it is possible to obtain columns of consolidated soil, the geometry of which is defined by the tool dimensions. In-situ soil mechanical mixing combined with water-cement mixture injected at medium-high pressure ensures a high quality strictly depend on the type and composition of the soil where the operation is carried out.

TDDT
(Trevi Directional Drilling Technology)

TDDT allows to create small-diameter holes *(50-200 mm)* of important length *(generally more than 40 meters up to a few hundred meters).*
The method has been developed by TREVI by implementing tools and techniques used in the oil and HDD industry. By increasing drilling accuracy, it allows to stretch the boundaries of conventional geotechnical works. TDDT ensures a wider range of field applications than conventional methods. It has been successfully used to drill accurate pilot holes for the construction of cut-off walls by means of secant piles for dam rehabilitation, or for artificial ground freezing and compensation grouting.

INJECTIONS

The injection technique is used in civil engineering to improve the hydraulic and mechanical characteristics of soils, rocks and artefacts *(masonry or concrete works)*.
From a functional point of view, we can distinguish interventions for the realisation of treatments:

- for provisional purposes, to enable excavations to be carried out in unstable ground or under the aquifer.
- with permanent function, for the consolidation of foundation soils, for the creation of waterproof screens, for the structural restoration of masonry or concrete works.

From an operational point of view, a distinction is made between loose soil and rock injections.

Injection into cracked rock is carried out directly into the open hole, while injection into degraded rock or loose soil can be carried out through valve tubes installed in the ground after drilling.
For injections into rock or loose coarse-grained soils, cement-based mixtures are generally used.

SOIL & SEDIMENT WASHING

Soils and sediments dredged from ports and access channels require specific treatment technologies to be recycled in a sustainable way.

Depending on the characteristics of the dredged sediment, different techniques are used:

- **Uncontaminated sediment**
  The recycling of sediment is maximised by using the grain size separation technique, such as sand and gravel mechanical screening *(use of vibrating screen)*, resulting in geotechnical stabilisation of the fine fraction.
- **Contaminated sediment**
  The recycling of the sediment is maximised by using the grain size separation technique, such as sand and gravel mechanical screening *(use of vibrating screen)*, the suspension of fines and process water is sent to the chemical-physical treatment plant.

The treatment plant has the following characteristics:

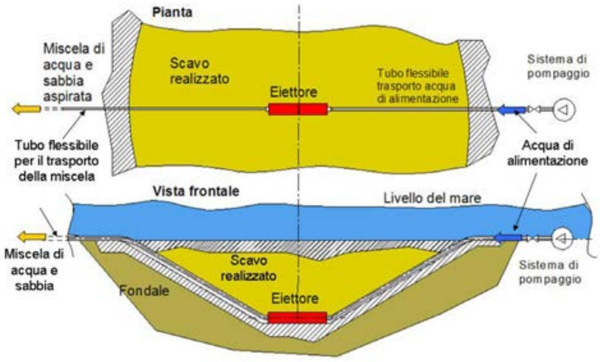
- Physical forces wash out contaminants and fine elements present inside the coarse fraction.
- Mounds of coarse material for recycling are obtained. A liquid stream containing silt and clay is produced and must be further treated.
- The system can handle high volume of liquid flowing through *(the systems are designed for 350-400 m^3/h)*.
- It works automatically in small spaces.

A cement grout, whose mix has been specifically designed for the sediment to be treated, can be injected directly into the centrifuge feed. The amount of binders added is automatically controlled by sensors that measure the flow rate of the sludge and its density. Customisation, uniformity and rapid hardening enable immediate disposal or recycling without the necessity of storage.

“LIFE” EJECTORS TECHNOLOGY

The innovative plant for seabed re-modelling consists of a set of devices, called ejectors, which constantly remove the sediments delivered to their operating area by transferring them to a nearby area where they do not impair navigation.

The withdrawal and subsequent transport of materials to be displaced takes place with no submersed moving equipment but with suitably oriented water jets that temporarily keep sediments suspended and convey them to the transportation and discharge pipeline. Ejectors are fixed to the seabed and do not impair navigation.



Views of the seabed re-modelling plant

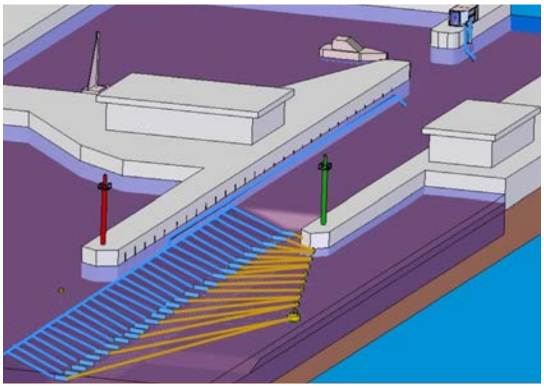
Hence, the whole plant is made up of:

1) a water pumping station which is used to feed ejectors with water pressure;

2) feed and discharge pipelines,

3) adjustment and control devices *(valves, instruments, etc…)*

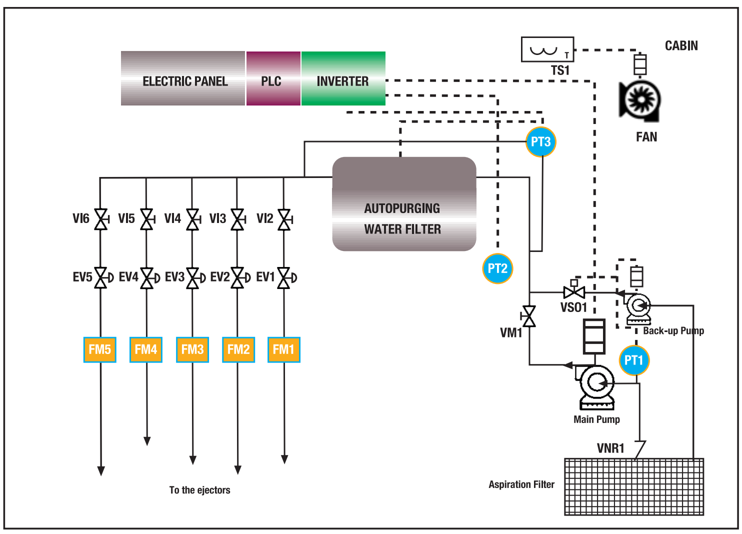
By means of one or more grids of ejectors, it is possible to operate in the areas affected by silting phenomena, thus carrying out a continuous removal *(24/7)* of the materials transported by currents and keeping the seabed at a set constant level.



Installation example (Riccione plant)

The plant’s dimensioning and the choice of ejectors depend on the type of specific application and, in particular, on:

- The size of the area affected by silting phenomena *(it does affect the number of ejectors)*
- The type of sediments *(it affects the area where each single ejector operates)*
- The length of the discharge pipeline *(it determines the ejectors’ minimum feed rate)*



5 ejectors pumping plant - P&I

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