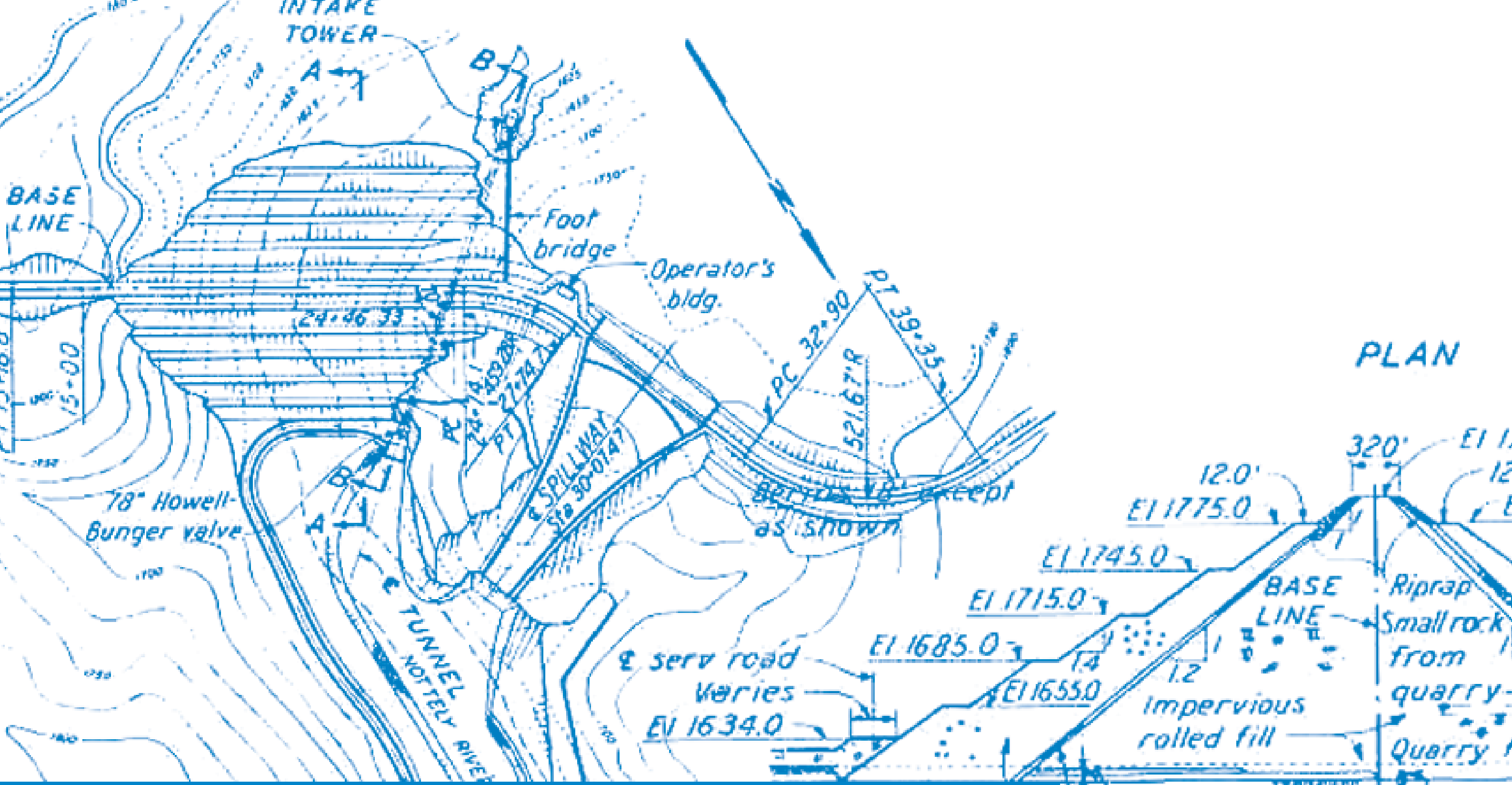
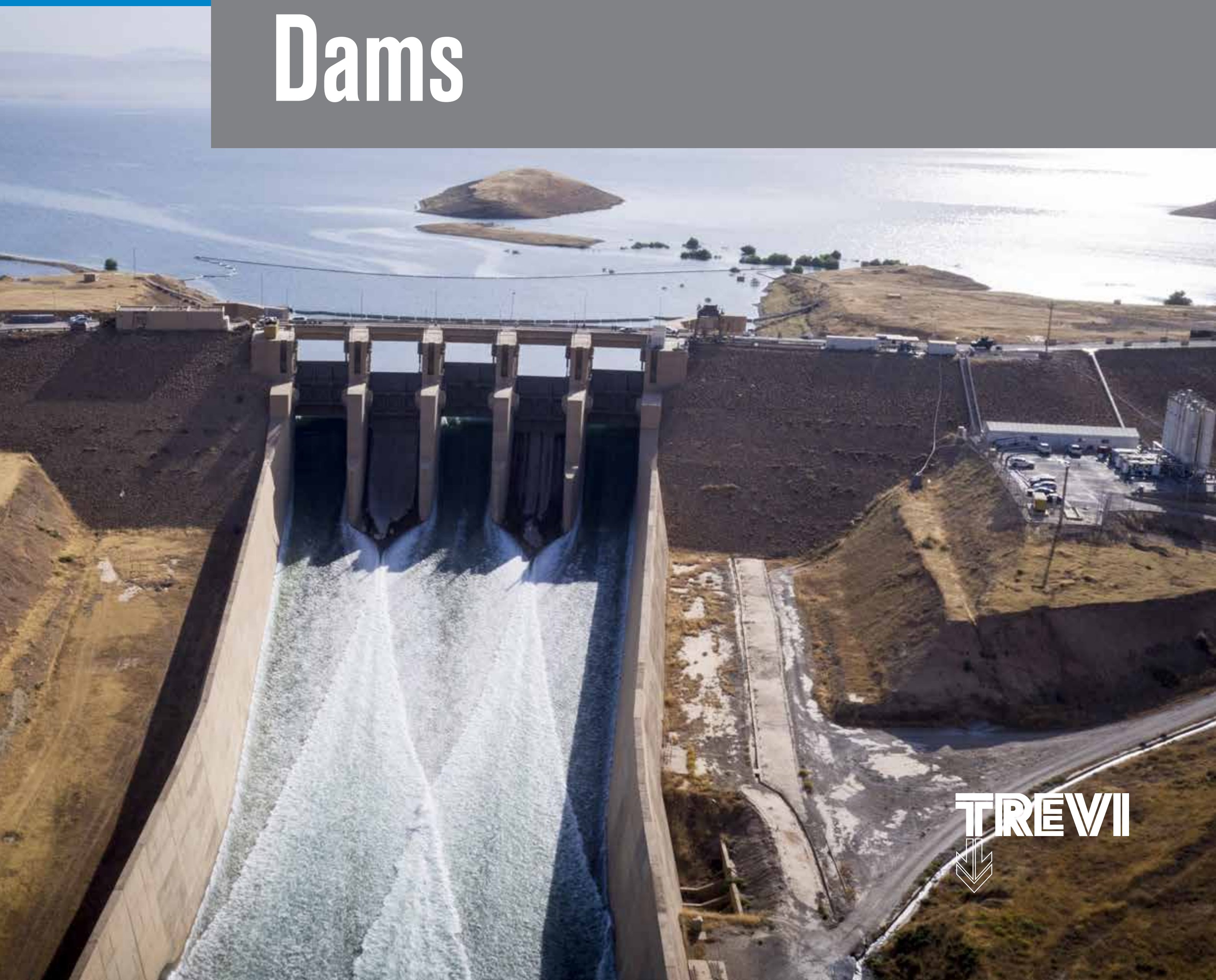


Trevi, world leader in dams rehabilitation and construction

Dams



TREVI

The Group

Today, 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 local cultures.

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

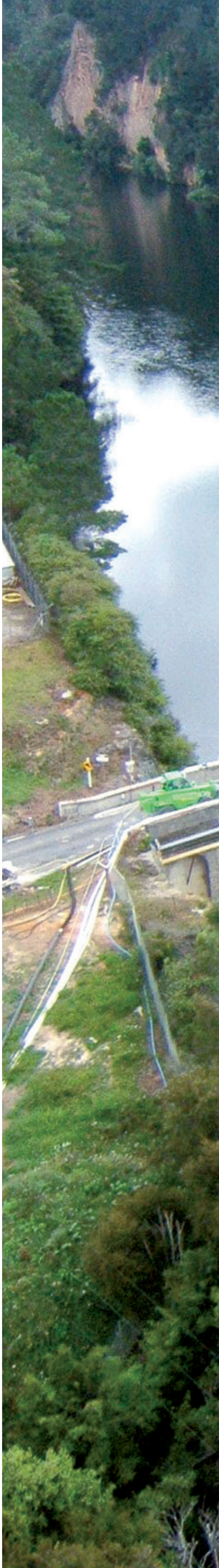
Trevi

Trevi has managed to satisfy the multifaceted requirements of the foundation construction industry, always showing a positive approach towards cultures different from its own. By 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 has spread out across faraway lands and as been held together by shared values and by a passion that has known no bounds. 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 parent company.

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



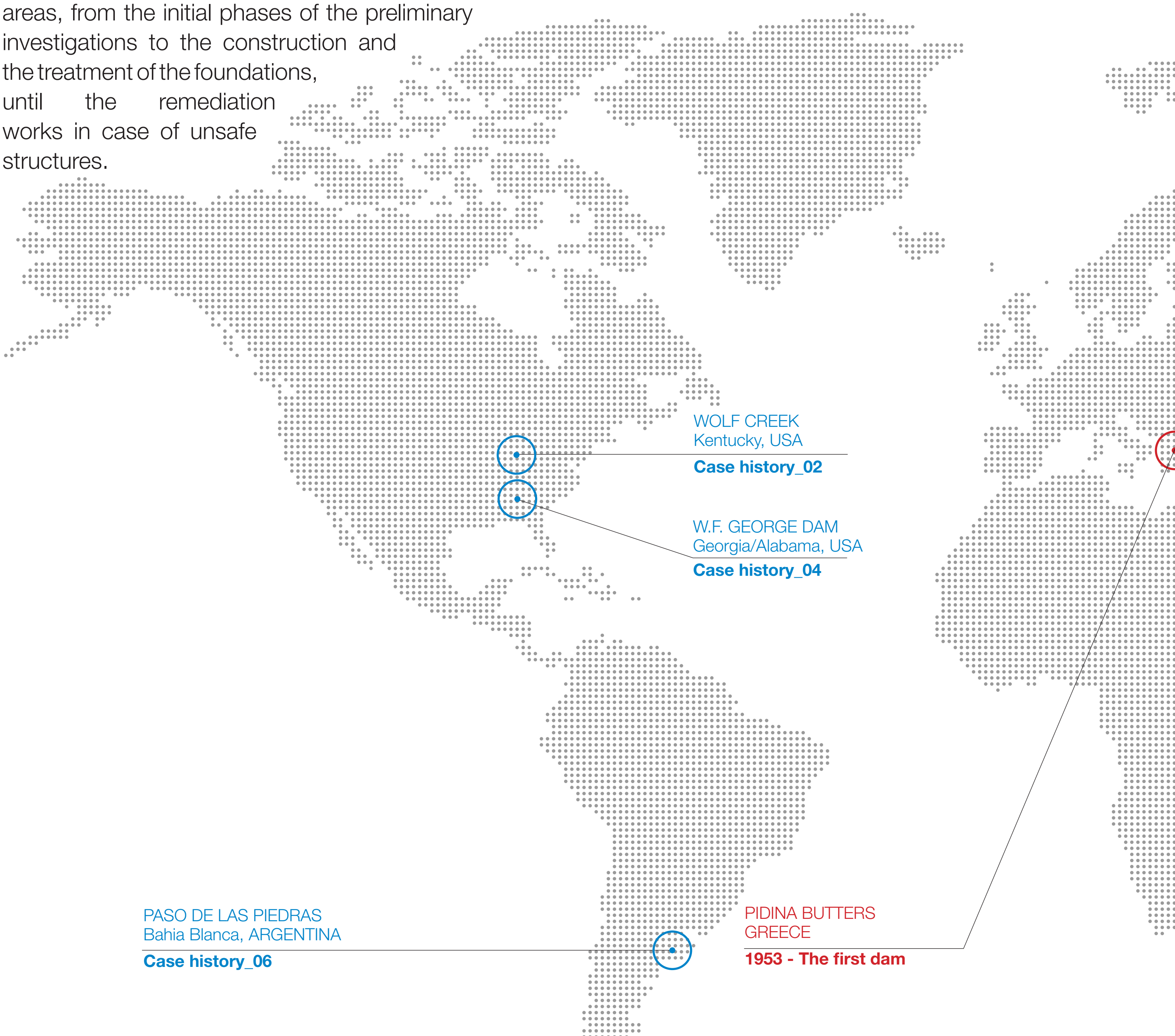
Cover: **Mosul Dam - Iraq**
Picture on the right: **Arapuni Dam - New Zealand**

Specialist Contractor for dams construction

The Trevi Group presence in the dam sector has a very long tradition, which dates back to more than half a century.

Since **1953, year of the first intervention to the Pidima Buttress Dam in Greece,** TREVI Group companies, worldwide leaders in dam construction and rehabilitation, have been committed to enhancing a crucial asset for mankind, that is water. Water plays a major role in world economy. Dams have multiple functions: they are built to generate electrical power, to feed canals and irrigation and water supply systems, to rise rivers water level in order to make them navigable or control their level during high water and low water periods, to create freshwater reservoirs and artificial lakes.

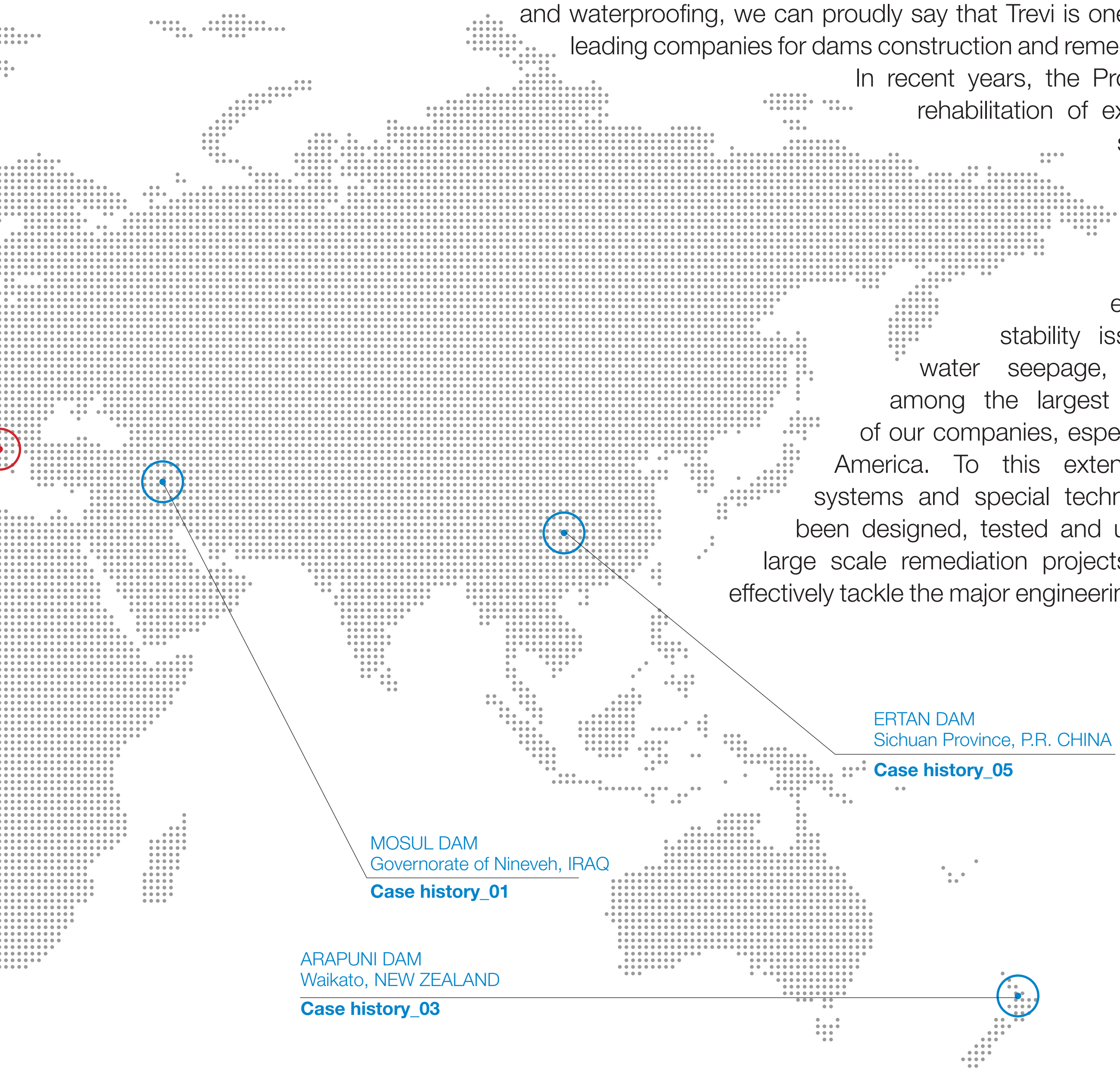
The Trevi Group companies participated directly to **more than 170 dam projects** all over the world, covering all the underground specialized areas, from the initial phases of the preliminary investigations to the construction and the treatment of the foundations, until the remediation works in case of unsafe structures.



Contractor for dams rehabilitation

After a long-standing and intense activity in the dams sector, both for construction and rehabilitation, Trevi has gained such an experience to be legitimately considered as a “specialist main contractor”, in the sense of taking over the whole project in case a dam should be rehabilitated or simply secured. In the developing countries the capability of building new dams is an important step toward industrialization. On the other hand, nowadays the maintenance and rehabilitation of old hydraulic structures turns out to be essential and Trevi has developed into a main contractor able to fulfil any possible requirement arising from the several and different fields of such complex projects.

Trevi benefits from a unique experience and know-how derived from the contribution to many of the most complex projects ever carried out in the five continents. With positive **Cut-off realized for more than 2,000,000 m^2**, hundreds thousands meters of secant piles, **more than 6,000,000 m of drilling and grouting** for consolidation and waterproofing, we can proudly say that Trevi is one of the world leading companies for dams construction and remediation works. In recent years, the Projects for the rehabilitation of existing dam structures experiencing stability issues due to water seepage, have been among the largest undertakings of our companies, especially in North America. To this extent, innovative systems and special technologies have been designed, tested and used in these large scale remediation projects in order to effectively tackle the major engineering challenges.



Mosul Dam, rehabilitation project
Gov. of Nineveh, IRAQ

US Army Corps of Engineers

Owner:	Ministry of Water Resources of Iraq
Engineer:	US Army Corps of Engineers
Main Contractor:	TREVI SpA
Completion Date:	03/2016 - 06/2019

Mosul Dam is the largest Dam in Iraq, located on the River Tigris in the Governorate of Nineveh. The Dam was constructed in the 80's under Saddam Hussein's rule.

It is an earth-fill embankment type with a clay-core dam, constructed for hydropower, flood control, water supply and irrigation purposes. Through its 113 m height and 3.65 km length, the reservoir has a storage capacity of 11.1 billion m^3 of water. **The main hydroelectric power station has an installed capacity of 750 MW.**
The discharge system includes two bottom outlet tunnels, a main concrete spillway with five radial gates and an emergency fuse-plug spillway, for a total capacity of 19,400 m^3/s.

Mosul Dam was constructed by a German-Italian Consortium from 1981 to 1986 under the Ownership of the Ministry of Water Resources (MoWR) of Iraq. Since its construction phase the Engineers were aware about the characteristics of the weak rock formation of the foundation, mainly consisting of marls and limestones, with soluble gypsum and anhydrite layers. Many cavities were found during the excavation works. Due to political pressure on the area and schedule, the works moved forward. Despite the execution of a blanket grouting and of a deep grout curtain, water seepage phenomena began immediately after the dam commissioning and the impounding.

The geological condition of the Dam's rock foundation, where continuous dissolution would be forming voids and water seepage networks beneath the embankment, drove the Engineers to envision a long term constant grouting treatment. Hence, a specific 3.0 m x 3.7 m grouting gallery, running along the longitudinal axis of the Dam for 2,160 m, was designed and constructed before placing the embankment.

By this way, the Ministry of Water Resources was engaged in a rehabilitation effort through a continuous maintenance grouting program in place since completion of the Dam construction.

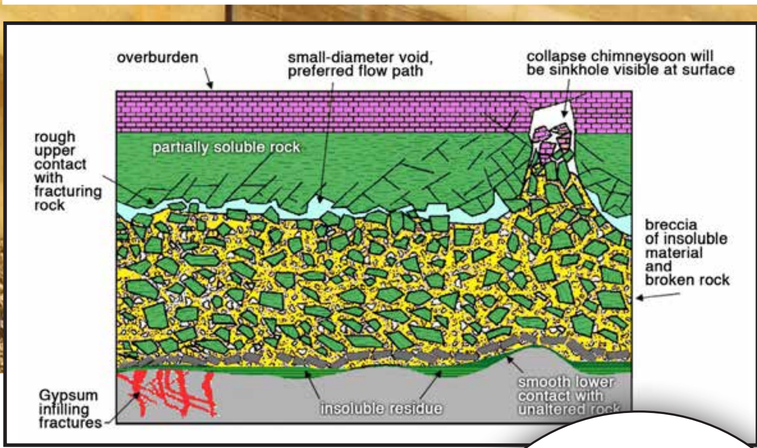
The current maintenance grouting contract was awarded to the Italian firm TREVI S.p.A. (TREVI GROUP), through an international bid launched by the Government of Iraq (GoI) in October 2015. The Contract between the Owner and TREVI was signed in early March 2016.

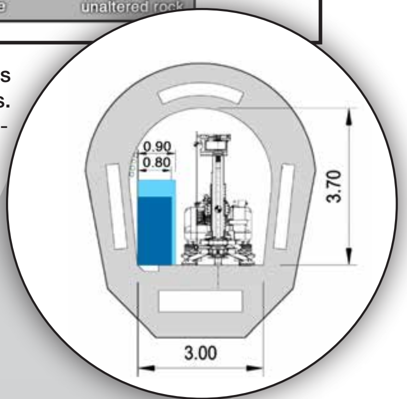
The GoI assigned the roles of Engineer and Contract Administrator to the U.S. Army Corps of Engineers (USACE), monitoring Mosul Dam since May 2015. The contract (fuel 362 million $) awarded to TREVI, amounting to about Euro 273 million.
Along with the maintenance grouting, TREVI was tasked also with the training of the Owner's personnel. A critical aspect of the contract was represented by the additional works for the rehabilitation of the bottom outlet tunnel *(i.e. guard gates and intake bulkheads)* where electromechanical fixing works and delicate diving operations were executed.

Multipurpose drilling rigs for specific drilling techniques and space constraints were deployed. SOILMEC supported TREVI in customizing the machines with special features. **In Mosul Dam Project, boreholes were executed with the rotary method down to a depth of 200 m, by means of PDC drilling bits, tricones *(from the surface only)* or core barrels with core recovery.**

The grouting works included the execution of a double grout curtain line along the Dam's axis, from both the grouting gallery and the crest, and a single grout curtain line along the eastern side of the spillway.

Grouted boreholes:	5.393 (403.000 m)
Grouted mixed:	40.833 m³
Workforce:	700 units
Man-hours worked: Worked without accidents	8.000.000





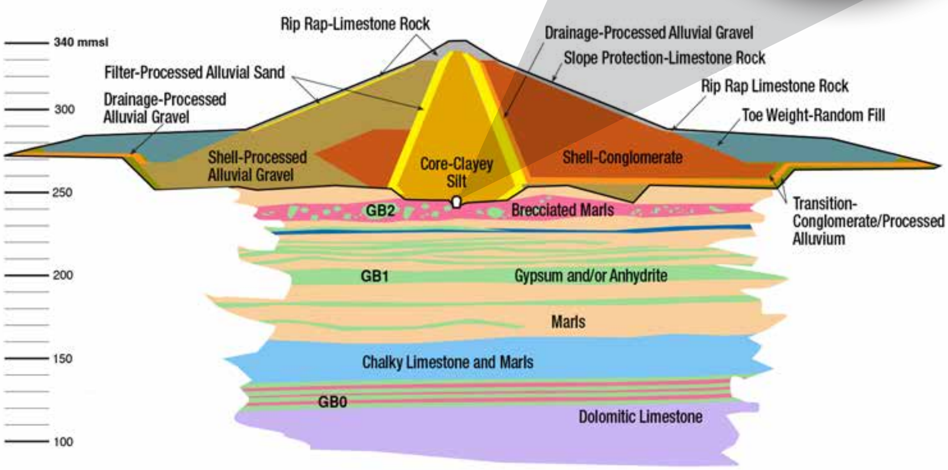
For the grouting works of Mosul Dam Project, Trevi developed the T-Grout system. T-Grout, where "T" stands for "Trevi", is a computer- automated web application allowing the remote management of grouting activities. Along with the already known characteristics of the common grouting recorders, T-Grout is able to remotely manage/operate the grouting pumps from a Control Room.

Beside drilling and injecting grout to strengthen Mosul Dam's geologic foundation, Trevi's contract also called for:

- An underwater inspection to evaluate structural integrity of the bottom outlet bulkhead guide slots and sills, bulkhead dogging beams, lifting eyes and underwater storage slots; and
- Repairs and rehabilitation of the facilty's massive bottom outlet structure, which houses two 2,500-ft-long and 40-ft-high bypass tunnels, associated bulkheads, gates, and mechanical and electronic controls, as well as the downstream plunge pool.

Trevi commenced the works with the war conflict against ISIS at a 13 km distance from the Dam. The presence of the Coalition Forces, together with the Italian Army, guaranteed the required security of the Project Area. Notwithstanding the strict security procedures, the works proceeded expeditiously with no delays.

The stringent technical, quality and HSE standards set forth by USACE, along with the security and climate difficulties, make the Mosul Dam Project a challenging and unique model worldwide in the field of underground engineering.



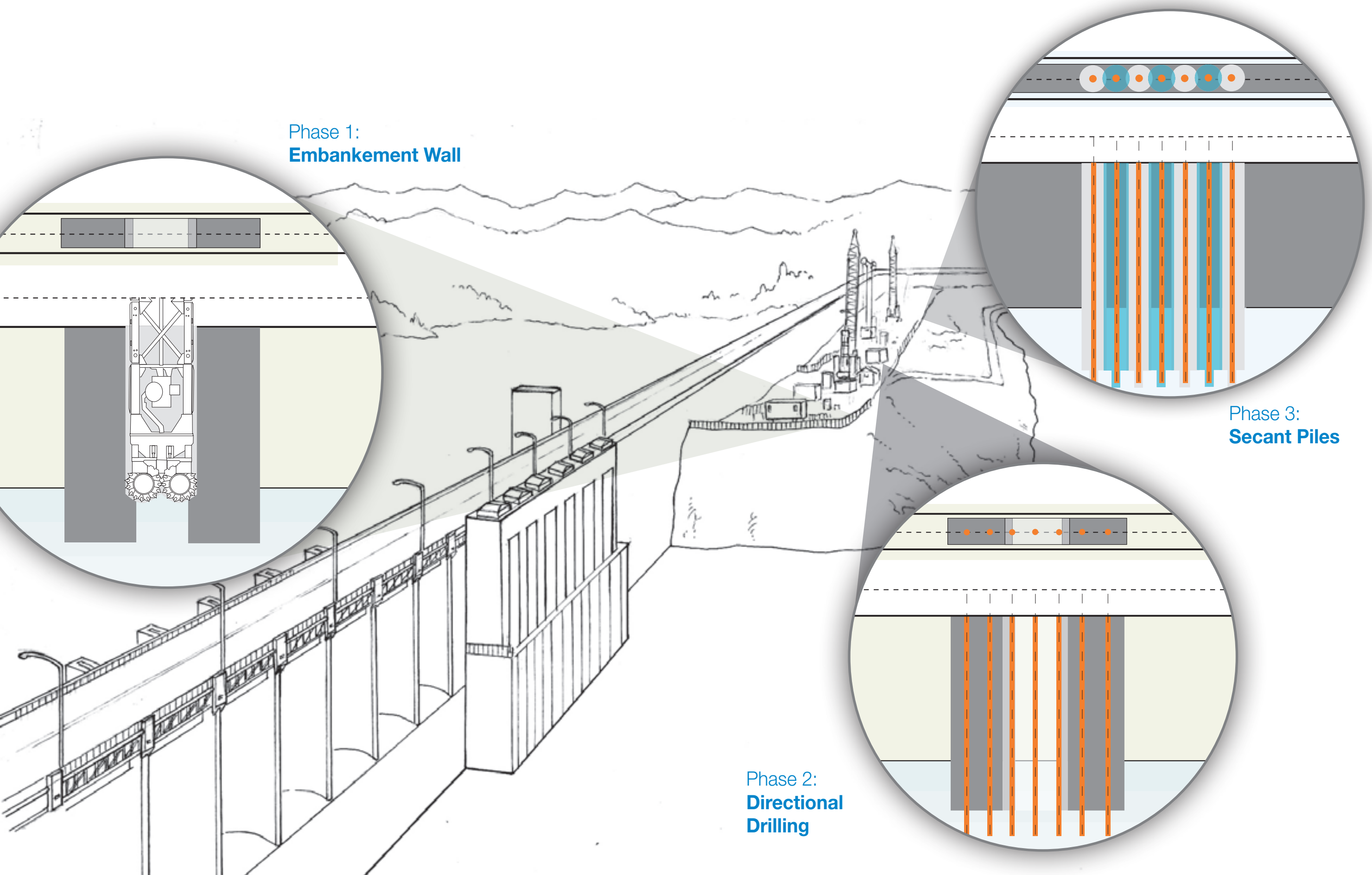
Wolf Creek Dam
Kentucky, USA

US Army Corps of Engineers

Owner:	US Army Corps of Engineers
Engineer:	US Army Corps of Engineers - Nashville District
Main Contractor:	TREVIICOS - SOLETANCHE JV (Treviicos - Trevi Group, Managing Parner
Completion Date:	August 2014 - expected project completion

The Wolf Creek Dam is vital to southern Kentucky and northern Tennessee, preventing the periodic flooding that once plagued the area along the 1,100 Km long **Cumberland River.** Designed and constructed during the period 1938-1952, the 1,750 m long dam has a maximum height of 79 m above founding level. Lake Cumberland, created by the dam, impounds 7.5 billion m3 and it is the largest reservoir east of the Mississippi River, the ninth largest in the US. The dam and its adjacent reservoir lie upon an heavily Karst bedrock foundation. After worrying signs of seepage were discovered, in late January 2007 USACE designated the dam as 'high risk' for failure, lowering by 20 meter the water level as a precaution. At the same time a major, ambitious remediation program was launched by the USACE Nashville District to bring back the dam to full operating condition.
The project for the construction of a 91,000 m^2 concrete barrier was awarded in 2008 to the Treviicos-led joint venture, Treviicos-Soletanche JV. A 0.6 m thick concrete barrier wall was successfully built to depths up to 85 m, in rock with strengths up to 250 MPa, requiring quality control measures that exceed by far the industry standards. Undoubtedly, the complexity of the project, coupled with the unprecedented stringency of the contract performance requirements, makes the Wolf Creek Dam Foundation Remediation Project the most extensive and complex dam foundation project so far executed in the world.
In order to safely protect the existing dam's body during the subsequent phases, a hydromill was used to install in the dam's embankment a 1.80 m thick Protective Concrete Embankment Wall (PCEW) touching the foundation rock. The concept of the PCEW, introduced to the industry by the JV in this project, is now being considered for other high risk dam remediation projects in USA. As the PCEW was completed in one area, several technologies were utilized to install the main barrier wall in a logical progression. Two of these technologies, designed and developed by the Trevi Group specifically for this project, are breakthroughs in the foundation industry. An original **Directional Drilling technique** was used to guide the secant piles of the Barrier Wall, achieving a maximum deviation of approximately 7 cm at a depth of 85 m. Then, an innovative Slot Pile System *(as known as the Arapuni System)*, was also tried. This method allows the sequential installation of several secant piles to form a slot to be concrete poured in one single phase, thereby increasing productivity and quality by radically reducing the number of cold joints between the piles. **At the end, the secant piles section of the barrier wall presented 1196 joints totaling about 85,000 linear meter of drilling.** Only one additional pile was required, remediating a non compliant pile installed in the Technique Areas during the demonstration phase of the methods. The outstanding quality of the barrier wall is the consequence of a management capacity in mastering the techniques pioneered on this job for installing, controlling, and measuring the position of wall elements. As a result of the exhaustive QA/QC system at Wolf Creek Dam Project, the JV was able to consistently exceed by far the Client's requirements for the barrier wall. By processing a large amounts of information, a 3-D as-built model was used to simplify the final evaluation of the barrier wall quality. As a result, the USACE's team was able to quickly complete a comprehensive technical evaluation, which provided analyses and documentation that typically would have taken several months of works to be prepared. During a meeting held in March of 2013, just six days after the completion of the barrier wall, USACE agreed to start raising the Wolf Creek pool.
USACE has stated that the Wolf Creek Dam project is a "model" for future dam remediation projects. In 2013 this project has been awarded the Deep Foundation Institute's Outstanding Project of the Year Award, and the Association of State Dam Safety Officials' (ASDSO) National Dam Rehabilitation of the Year Award.

Drilling & Grouting:	55.000 m
Barrier Wall:	91.000 m² maximum depth 85 m
Directional Drilling:	85.500 m



ARAPUNI DAM, remediation work
Waikato, New Zealand

Owner:	Mighty River Power
Main Contractor:	Alliance Trevi - Brian Perry Civil Eng. - Mighy River Power
Completion Date:	2005 - 2007

In 2007 Trevi completed the construction of a 90 m deep secant pile cut-off wall where was compelled to strive to push the envelope to improve existing technologies.

The owner and operator, Mighty River Power, had been planning this project for several years with the technical assistance of the Dam Watch Services. To achieve the robust and verifiable solution required, they recognized that the development and application of unproven technologies would be necessary.

Mighty River Power chose to adopt a formal Alliance procurement model and, after a series of interviews with few International Foundation Engineering Contractors, they chose the Italian Foundation Specialist Trevi S.p.A. and the local specialist civil engineering contractor Brian Perry Civil as their alliance partners to deliver the NZ$ 20 million project.
After a two years' work, early monitoring indicated that the cut-off wall was extremely effective.

The dam site is located within an area characterised by the presence of multiple ignimbrite flows deriving from volcanic eruptions occurred over the last 2 million years. Two ignimbrite units form the gorge walls. The younger Mananui Ignimbrite is present, as upper unit, on the right abutment only, while Ahuroa Ignimbrite is present on both abutments. Both ignimbrites are columnar jointed, weak to moderately strong point-welded tuff.
The main dam footprint is founded on a 40-50 m thick layer of Ongatiti Ignimbrite, a point-welded tuff. The upper part of the unit is very weak, with unconfined compressive strength between 2 and 6 MPa, while below the original dam's cut-off wall the Ongatiti is considerably stronger (up to 28 MPa) and it is identified as the "hard zone".

Arapuni Dam is a 64 m high curved concrete gravity dam, with a crest length of 94 m, across the Waikato River bed. The dam, commissioned in 1929, forms the reservoir for a 186 MW hydro-electric power station.

The original characteristics of the dam include concrete cut-off walls and a network of porous *(no-fines)* concrete under drains at the dam/foundation interface. The under drain is the main uplift control at the dam foundation interface. The original cut-off walls extend to a depth of 65 m below the dam crest and also into the left and right abutments of the dam. No grout curtain was installed during the original construction.

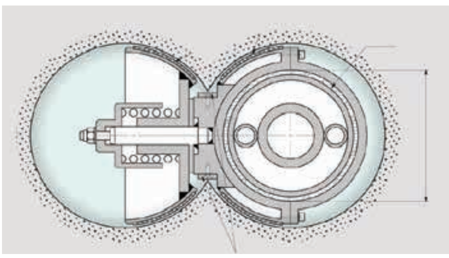
In June 1930 the reservoir was completely dewatered, due to the development of a large crack in the headrace channel near the powerhouse, whilst this was being repaired; a grout curtain was constructed along the upstream heel of the dam and along the front of both abutment cut-off walls. Mighty River Power required an upgrade of the dam foundation seepage control measures where either of the following was present:

- Highly erodible joint infill vulnerable to piping erosion.
- Near-lake pressure in areas under the dam due to open fractures hydraulically connected to the reservoir.

The aim of the upgrade was to significantly reduce the risk and severity of further piping incidents and to control high pressures under the dam.
Furthermore, the objective was to complete remediation works without stopping power station operations (i.e. keep the reservoir at normal operating levels). Dam Watch identified four fissure sets that required a treatment to either fill open fissures or replace erodible infill with suitable materials to form a durable barrier.

The Arapuni Dam Alliance chose a secant pile methodology aimed at achieving the technical objectives, such as constructability, as well as ensuring dam safety during construction. The design envisaged four discrete cut-off walls instead of a continuous one.

*At the **New Zealand Contractors Federation 2007** conference the project received a **Shell Environmental Excellence merit award** "given the project was competing with significantly larger high profile projects this is testament to the early planning and culture of the alliance site team".*

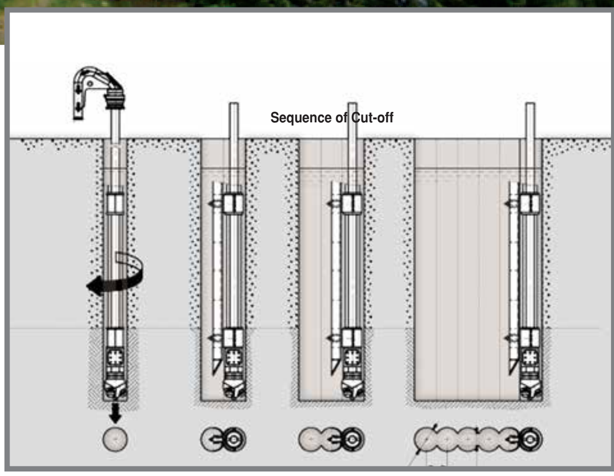


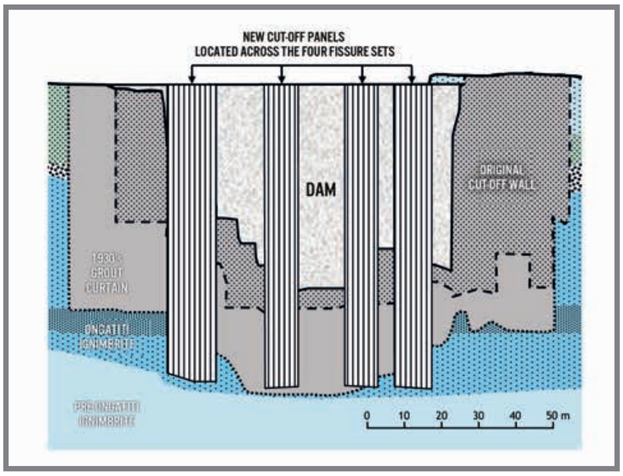
The basic method involved construction of 400 mm diameter secant piles at 350 mm diameter centres to depths of almost 90 m from the dam crest. To provide the required cut-off, the critical factor was to maintain and verify piles' overlap.

A drilling verticality accuracy better than 1 in 3600 would be required to ensure adjacent piles' overlapping; using conventional piling equipment 1 in 200, which is difficult to achieve and, even by using directional drilling, the overlap was far from guaranteed.

The solution developed by Arapuni Dam Alliance was a guide attached to the drill string which is located in the previously drilled hole. The guide and the drilling system were studied and built in Italy by Trevi and Soilmec, the Trevi Group manufacturer of specialized equipment.

The Arapuni Dam Alliance has successfully constructed a concrete cut-off wall under an operating dam, without adversely affecting dam safety or electricity generation. Also the construction of overlapping/secant piles to such depths represents a significant breakthrough in technology and experience in this field.





Walter F.George Dam
Georgia/Alabama, USA

US Army Corps of Engineers.

Owner:	US Army Corp of Engineers
Engineer:	US Army Corp of Engineers
Main Contractor:	Trevi - Rodio JV *(Rodio is part of the Trevi Group)*
Completion Date:	2004

The Walter F. George lock, dam, and powerhouse structures, located on **the Chattahoochee River near Fort Gaines**, GA, experienced serious seepage problems since the beginning of the impoundment of the reservoir in 1963, which became progressively more severe with time. The problems were originated by the development of solution channels concentrated near the top of the limestone foundation rock and by under seepage through the permeable section of the alluvial overburden.

In order to stop the seepage a 560 m long concrete wall has been constructed by Trevi-Rodio JV immediately upstream of the concrete portion of the dam and extending into sections of both embankments. The project has involved a preliminary exploratory and mortar grouting campaign aimed at gathering additional information on the rock characteristics and, at special locations, at intercepting and plugging the main solution channels. Most of the drilling and grouting works were carried out from barges floating over the lake.

The Cut-off in front of the main dam consisted in **15,300 m^2 secant piles wall**, constructed from barges floating on 30 m deep water. It was the first time in the USA that a **secant pile wall was installed in water depths up to 30 m**. The maximum Cut-off depth, from the lake bottom, was 43 m. The piles, **1,270 mm diameter**, were bored with reverse circulation drilling rigs installed on temporary steel casings. An innovative guiding system, with steel templates connected to the dam's buttresses, was designed by the JV in order to assure the necessary alignment of the piles, though working from the lake side.

On the right and left dam's embankments, the Cut-off was constructed using a hydromill cutter. In these zones the **diaphragm wall, 0.80 m thick, was as deep as 64 m**. Rocks with high UCS in excess of 130 MPa were recorded into the lower sandy limestone strata.

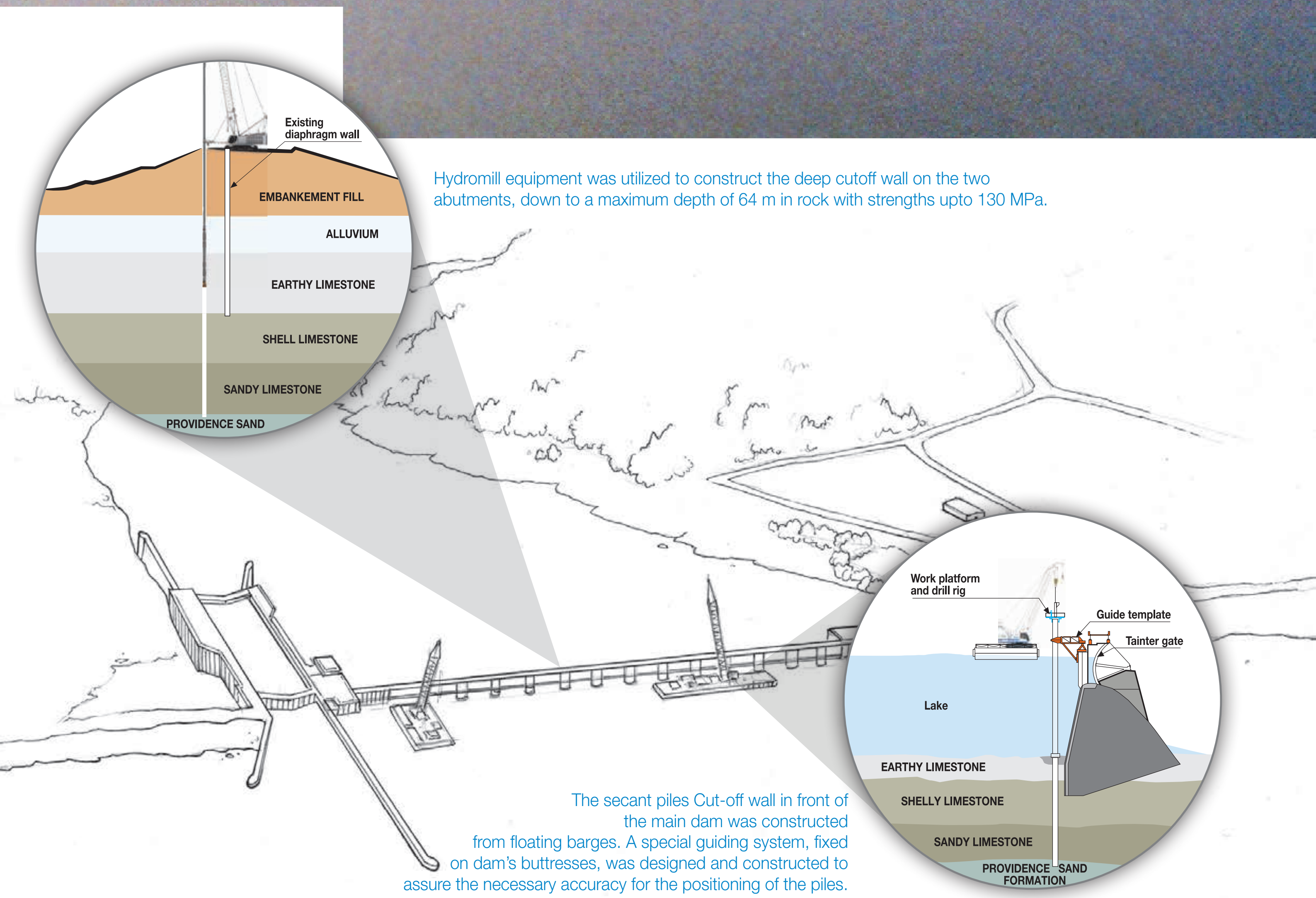
The Cut-off alignment passed through the concrete walls of the existing lock structure. A combination of a hydromill cut into the concrete steeply inclined surfaces, and of secant piles underneath was utilized for the Cut-off construction in this particular area.

The piezometer readings taken downstream and upstream the dam, after the installation of the Cut-off wall, showed a significant drop, thus indicating the great quality of the works.

The project was completed more than 8 months ahead of the contract schedule: this has been possible thanks to the excellent coordination of the different work phases, the knowledgeable team and the beneficial partnering approach between USACE and the JV.

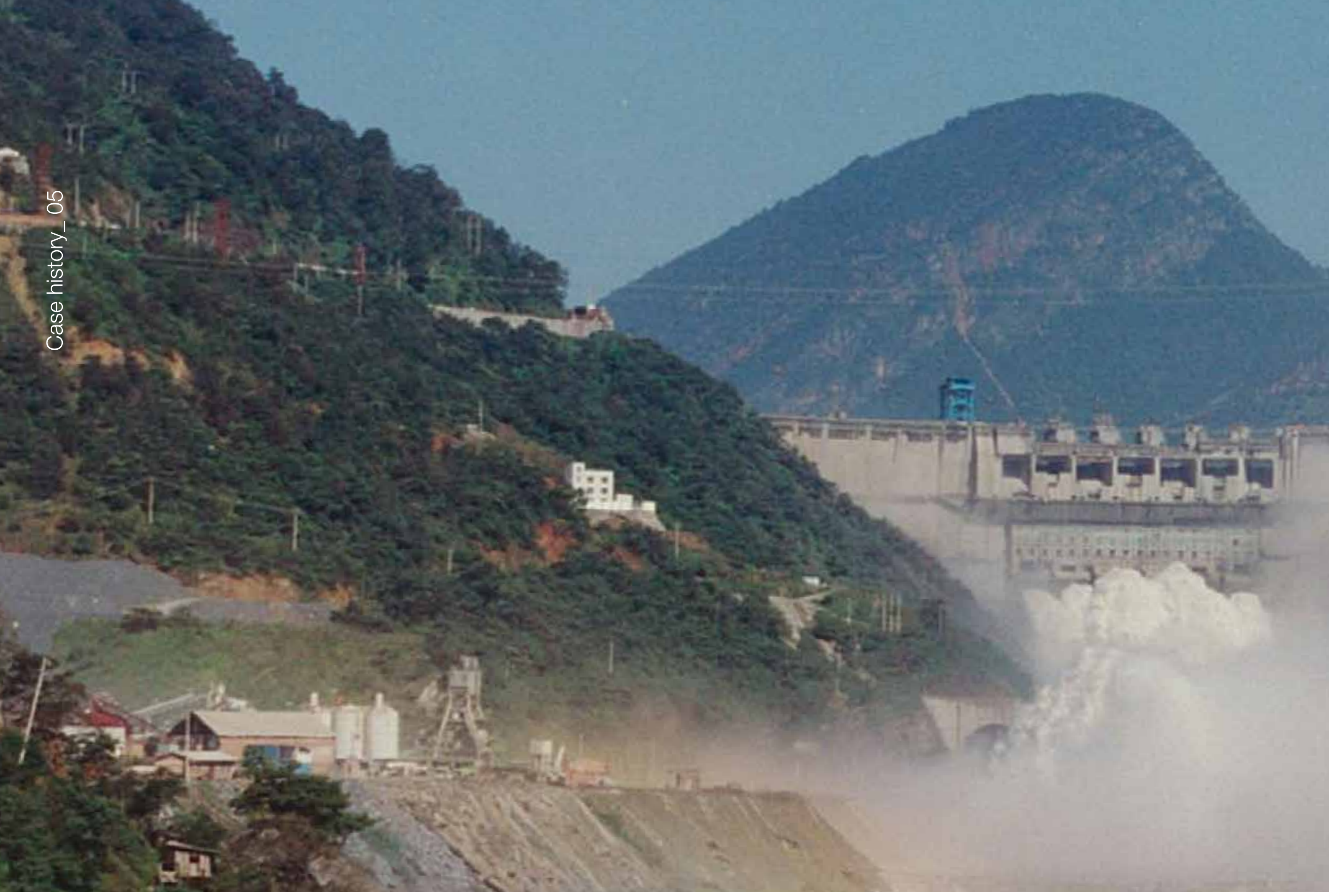
Together with other acknowledgments, the 2003 COE South Atlantic Division Contractor Safety Award of the Year was awarded to Trevi-Rodio JV, for working more than 900 days and 535,000 man-hours without a lost time accident.

Drilling, Grouting, Coring:	4180 m
Secant piles:	15.300 m^2
Diaphragm wall:	9.300 m^2



Hydromill equipment was utilized to construct the deep cutoff wall on the two abutments, down to a maximum depth of 64 m in rock with strengths upto 130 MPa.

The secant piles Cut-off wall in front of the main dam was constructed from floating barges. A special guiding system, fixed on dam's buttresses, was designed and constructed to assure the necessary accuracy for the positioning of the piles.



Ertan Dam
Sichuan Province, P.R. of CHINA

Owner:	Ertan Hydroelectric Development Corporation
Engineer:	Chengdu Hydroelectric Investigation & Design Institute Studio Sembenelli
Main Contractor:	Ertan JV (Impregilo Sponsor)
Specialized Sub-contractor:	Trevi Construction Co. Ltd. - Hong kong
Completion Date:	April 1994 (Lot A) April 1999 (Lot B)

The Ertan Dam is one of the series of hydroelectric power plants to be erected **along the Yalong River**, a tributary of the Yangtzé River. The dam is situated 750 km from Chengdu, capital of Sichuan province, and about 2,000 km from Beijing. The double-curvature parabolic arch dam has a maximum height of 240 m and a lenght of 775 m.

The total volume of concrete is about 4.2 million m^3. The average dam's width is 11 m at the crest and 56 m at the foundations. The underground powerhouse has a total capacity of 3,300 MW.

The Trevi Construction Company of Hong Kong, a subsidiary of the Trevi Group, was awarded two contracts at the Ertan dam project: the construction of two jet grouting cut-off walls at the upstream and downstream cofferdams and the grout curtain and drainage into the dam's foundation rock.

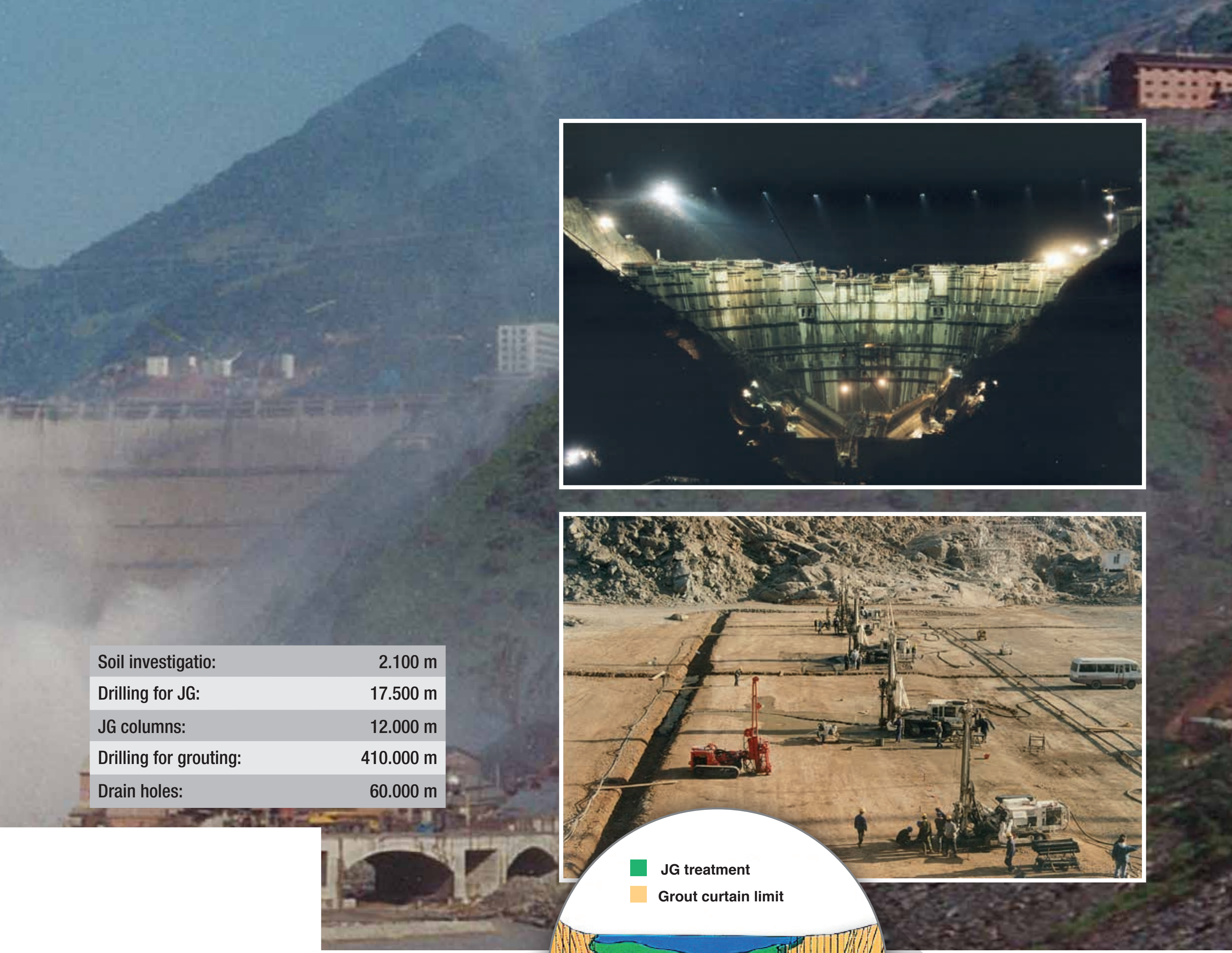
Both contracts had to be completed during the dry season's period lasting seven months, and only three months were available for the construction of the cut-off structures.

Jet Grouting (Lot A)
The JG curtains were carried out below the upstream and downstream earth cofferdams, 62 m and 30 m high respectively. By mobilizing and operating all the required equipment, Trevi was able to install 12,000 linear meters of JG columns, 1.5 meter diameter, with a centre to centre spacing of 1.0 meter. Drilling in difficult soil required the use of roto-percussion cased drilling. The parameters of the installation were determined through a specific field test carried out prior to the starting of the production columns.

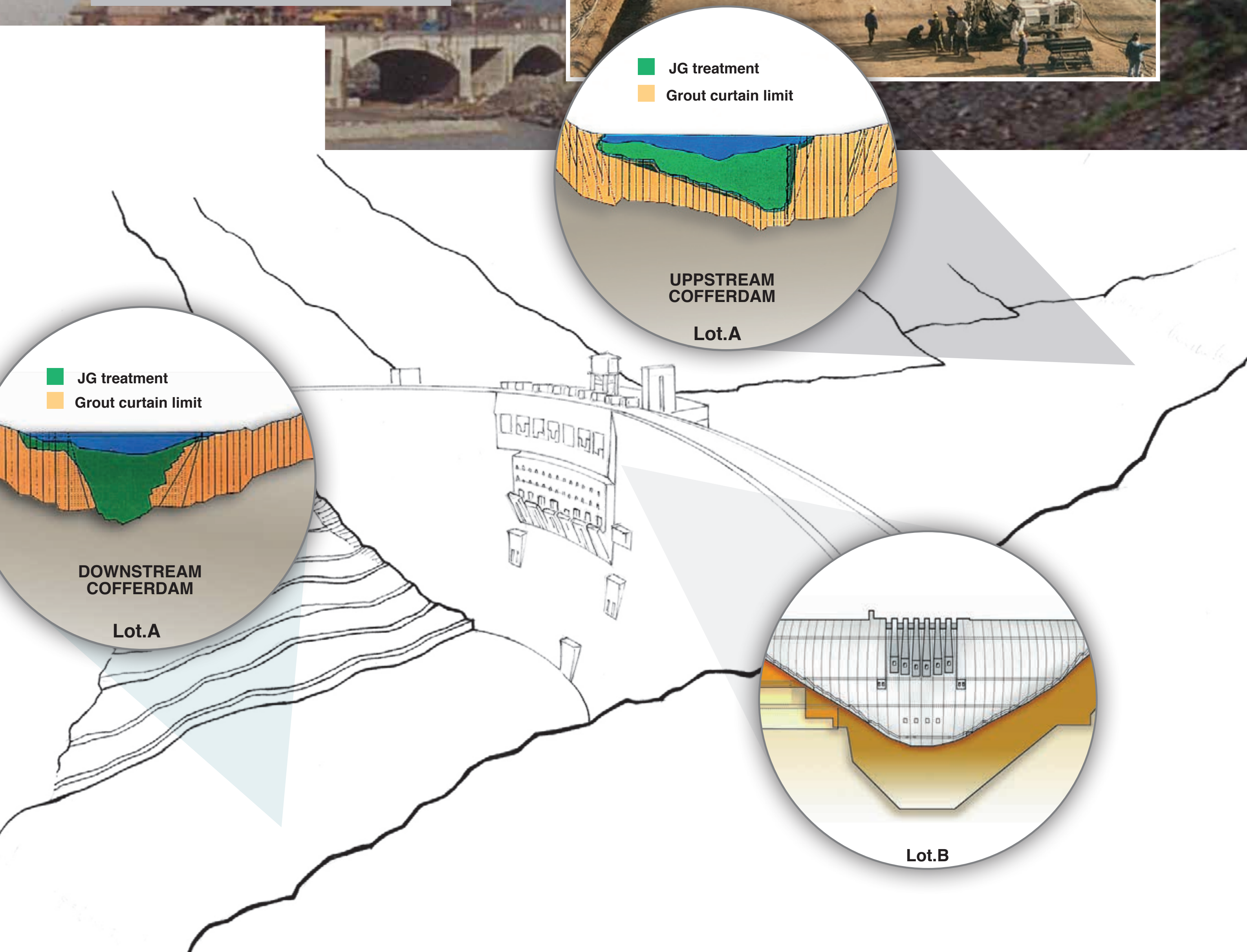
The quality of the work was verified and confirmed by the piezometer readings as well as by extensive corings into the JG columns. The effectiveness of the installation was thoroughly ascertained.

Grout Curtain (Lot B)
The grout curtain and the consolidation works underneath the main dam consisted in 215,000 m and 157,000 m of drilled boreholes respectively, with a total of 15,600 ton of injected cement. In addition, 60,000 m of drainage curtain were drilled and installed.

For the execution of both contracts Trevi co-operated with a specialised local company "The 8th Hydroelectric Engineering Bureau of Changsha" *(Hunan Province)*.



Soil investigatio:	2.100 m
Drilling for JG:	17.500 m
JG columns:	12.000 m
Drilling for grouting:	410.000 m
Drain holes:	60.000 m



Paso De Las Piedras Dam
Buenos Aires Province, Argentina

Owner:	Autoridad del Agua de la Provincia de Buenos Aires
Main Contractor:	RED Ingenieria
Completion Date:	1996 - 1999

Paso de las Piedras Dam is located in Argentina, 70 km **northwest of Bahía Blanca**, a city which including its suburbs reaches 500,000 inhabitants.
The Dam was built to supply potable water to Bahía Blanca city and its suburbs. The structure was constructed on a rocky Paleozoic quartzite ridge where the Sauce Grande River has excavated a big cut that was filled by sediments, mainly formed by soft to partially cemented silts, clayey silts, sand and coarse gravel. The project was completed in the late 1970's.
A poor design and some construction defects caused several problems even during construction. Sand boiling, seepage, fines displacement and regressive erosion forced the Ministry of Works and Public Services of Buenos Aires Province to study and develop a remediation program which was issued for bid at the end of 1994.
In 1996 the dam repair project was awarded for the execution of the following works:

- Drilling and installation of new piezometers for 1,500 m
- Installation and operation of the Automatic System of Acquisition of Dam Instrumentation Data.
- Additional soil investigation campaign for 1,000 m
- Installation of a slurry wall on the left abutment and access to the spillway for 13,500 m^2
- Execution of a 47,000 m^2 Jet Grouting Triple Fluid Cut-off Wall.

The scope of the Cut-off wall aimed at minimizing infiltrations through the dam's structure and underneath it. This was required in order to be able to use the reservoir to its full capacity, as well as to provide the dam with suitable safety parameters.

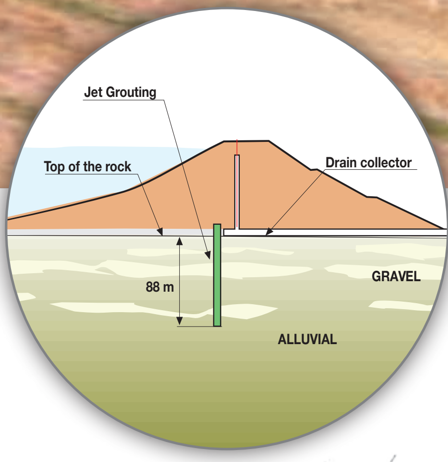
Jet Grouting Cut-off Wall

The Cut-off wall is located approximately 12 m upstream of the centre of the dam. The peculiarity of this project is that, for the first time ever, the jet grouting technique has been adopted to install a permanent cut-off wall using a single row of columns inside an active dam without lowering the water level in the reservoir. The triple fluid method was selected in order to fulfil the stringency of the acceptance criteria set forth in the contract specifications.

The cross section of the dam show's the location of the Cut-off wall.
To meet this difficult challenge, a very tight Quality Control procedure was adopted to closely monitor the installation of every single column from the drilling and grouting stages to its completion. Drilling was done first, then the holes where backfilled with a plastic mix, and afterwards each column was designed with different jet grouting parameters to ensure an effective continuous overlap between columns and thus the continuity of the Cut-off wall inside every type of soil.

The design considered the following parameters: column location, vertical deviation, soil type and geometry of the already installed columns. The geometry was determined in function of the actual energy applied to each type of soil for each column.The verticality of each hole was measured by means of a biaxial inclinometer. Measurements were carried out every 1.5 m to a maximum depth of 88 m. Such verticality data were stored and processed in order to obtain the specific deviation of each boring. Finally, the boring was filled with a plastic mix to keep it open until grouting operations were completed.
Once all the data for designing one column was compiled, they were processed by an algorithm and software specifically designed for this job site. This procedure made possible to quickly and efficiently design each single jet grouting column to address the geology and also the geometry of the already installed adjacent columns. The installed diameters varied from 1.60 m for primary columns to 2.40 m for secondary and tertiary columns.

Soil investigation:	3.500 m
JG Cut-off:	41.000 m^2
JG columns:	34.000 m
Plastic concrete diaphragm wall:	11.800 m^2
Grout curtain:	3.000 m



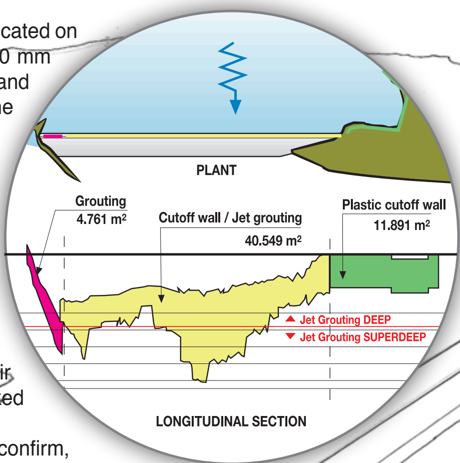
The Jet Grouting Cut-off wall reached a depth of 88 m to become the deepest Cut-offwall ever installed with this technology, inside an active dam.

Plastic diaphragm wall in the left abutment

The working method employed for the construction of the diaphragm wall was the excavation of panels by means of a 10 ton, 0.60 m wide and 2.70 m long, cable operated rectangular clamshell grab. The trench was excavated with the aid of bentonite based slurry and the filling material was a cement-bentonite mix.

Drilling and grouting in the right abutment

The technique used for the treatment of the quartzite located on the dam's right abutment consisted in the drilling of 60 mm diameter holes in order to cross the rock open cracks and subsequently grout them in 5 m long sections, using the up-stage method. The distance between primary and secondary core borings was 3 m, being reduced to 1.5 m when tertiary borings were necessary.



Confirmation of the Success of the Repairs

Although upon completion of the Cut-off wall, a group of experts determined the compliance of the repair works with the design requirements set forth in the technical specifications, approximately 10 months after the completion of the repairs, due to the occurrence of an historic flooding event, the reservoir reached its highest elevation and the spillway worked during several days at maximum capacity.
This event allowed the experts and the client to confirm, by analyzing the behaviur of the dam's instrumentation, that their design was correct and that the recently completed repairs have successfully achieved the intent of the project.
This was also physically confirmed during the flooding events of 2002 and 2003.

Hydromill technology for the new millenium

Construction of deep and ultradeep concrete walls

Trevi Group has once again made a major breakthrough in the field of subsoil engineering. In the second half of 2012, thanks to the employment of an innovative SOILMEC hydromill *(Tiger Type)* and to the cooperation between Trevi *(operating in the service sector)* and Soilmec *(designing and manufacturing machines for subsoil engineering)*, the Group succeeded in completing **Cut-off walls down to 250 m at Gualdo Site**: a goal never attained before and deemed inconceivable up to now, since it redoubles the currently-known potential of said technology.

This important experimental test was scientifically supported by the Politecnico di Torino *(coordinator)*, by the Università di Bologna *(geotechnics)*, and by the Università Politecnica delle Marche *(preliminary tests and quality control on materials)*.

During the test, 150 and 250 mm deep panels with a size of 3,2 x 1,5 m were installed. The deviation from verticality measured at the bottom of excavation *(250 m)* was 30 cm respect to the longitudinal axis *(0,12 %)* and 20 cm respect to the transverse axis *(0,10 %)*; rotation turned out to be always lower than 2° *(see bottom rig fig).*

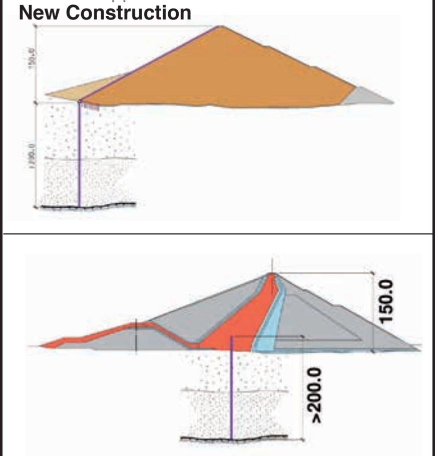
NEW APPLICATIONS

The results achieved, besides further confirming the great synergy between the Group's Divisions, also provide a chance to participate in the most complex International job orders. In particular, the new technology devised by Trevi Group allows designers to face and solve complex geotechnical problems concerning underground infrastructures and hydraulic works that require the construction of deep cut-off walls.

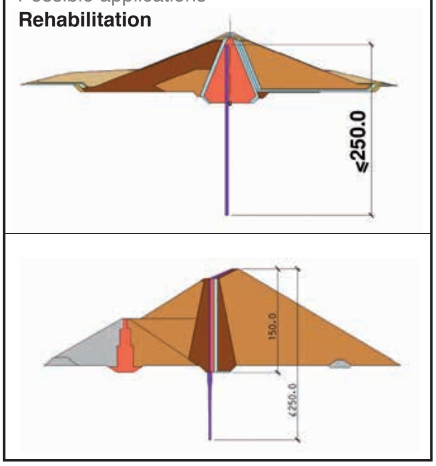
The following sectors are mainly involved:

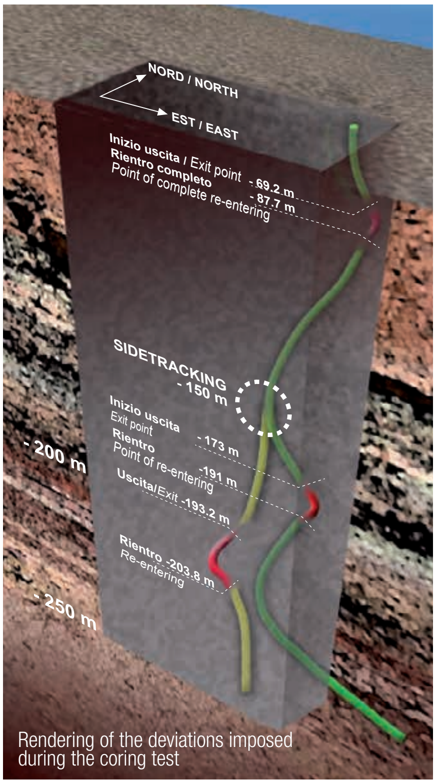
- **dams;**
- **hydraulic confinement of polluted sites;**
- **support infrastructures for shafts, underground stations, toe-of-slope thrusts.**

Possible applications
New Construction



Possible applications
Rehabilitation





Rendering of the deviations imposed during the coring test

Test field

Special technologies application
for dams construction and rehabilitation

DIAPHRAGM CUT-OFF WALLS

Diaphragm Walls, also known as Slurry Walls in the USA, are temporary or permanent continuous walls constructed in a deep vertical trench excavated in the ground with the support of a stabilizing fluid *(bentonite or polymer slurry).* Applied for the first time in the 50's, Diaphragm Walls are now commonly employed worldwide as soil retaining structures and/or impervious barriers *(Cut-off Walls)*. While Cut-off walls designed to have also a structural function are always made of reinforced concrete, plastic walls are just used to intercept groundwater seepage, therefore the excavated trench is usually filled with a low-strength high-plasticity concrete or a mix of water, cement and bentonite, generally known as self-hardening slurry.

SECANT PILES CUT-OFF WALLS

Cut-off walls can be formed also by using interlocked piles.

Secant Piles are temporary or permanent foundation piles arranged in a line and executed at a centre to centre distance of less than their diameter. By this way, a continuous underground wall is obtained. Secant Piles are typically installed following an alternating sequence, thus firstly executing two "primary" lateral piles and then the "secondary" one in-between. The required penetration into the bodies of the already cast "primary" piles is usually achieved by means of a heavy-duty core barrel or by rotating a continuous casing. Secant Piles are used as an alternative to diaphragm walls, both as soil retaining elements for the construction of underground structures and as an impervious barrier to confine a soil volume or to intercept groundwater flow.

DRILLING & GROUTING

Drilling & Grouting is a ground improvement method consisting in filling, by low pressure injection, the interstitial voids of a coarse-grained soil or the fissures of a rocky formation with a cementing mix.
According to the magnitude of the voids or fissures, cement-based suspensions or chemical solutions are commonly used for this purpose.

JET GROUTING

Jet Grouting is a relatively recent ground improvement method that involves the disaggregation of the soil and its mixing in place with, and partial replacement by, a cement grout mix. Soil disaggregation is achieved through high energy jets of one or more fluids, one of them being the grout mix itself.
Because of its peculiar characteristics, the range of soils that can be treated by this technique is extremely wide, spanning from peaty clays to gravel.

HIGH MOBILITY GROUTING

High mobility grouting is used to reduce water seepage through fissured rocks. The grout shall be stable, and shall generally incorporate cement, bentonite and special admixtures. A range of different composition of grout is designed to suite the local geological conditions. In modern projects, the operations are assisted by computerized systems to control and record, the grouting parameters, i.e. pressure, volume, flow rates, etc..

LOW MOBILITY GROUTING

Low mobility grouting is aimed at backfilling cavities and compacting soft soil. A thick, stiff and stable mix is pumped through casings after drilling, performing grouting stages in up-stage mode.

COMPUTERIZED RECORDING DEVICE DMS

Modern drilling rigs are equipped with computerized device to record and monitor drilling parameters. SOILMEC machines feature the DMS *(Drilling Mate System)*, which collects and shows in real time an endless list of parameters, allowing the driller to have full control of the machine and of the drilling operations.
Piling rigs, cranes, and hydromills feature special software to store the data.
After processing the data, the verticality of each element can be plotted and as built drawings can be derived, for QA/QC purposes.

DIRECTIONAL DRILLING FOR CORING

Final controls on the wall continuity can be performed using navigation instrumentation, to precisely direct some check holes. Instrumentation inherited from the Directional Drilling can be fruitfully used to survey the actual position of the holes, and to direct the corings to designed positions selected by designers.

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