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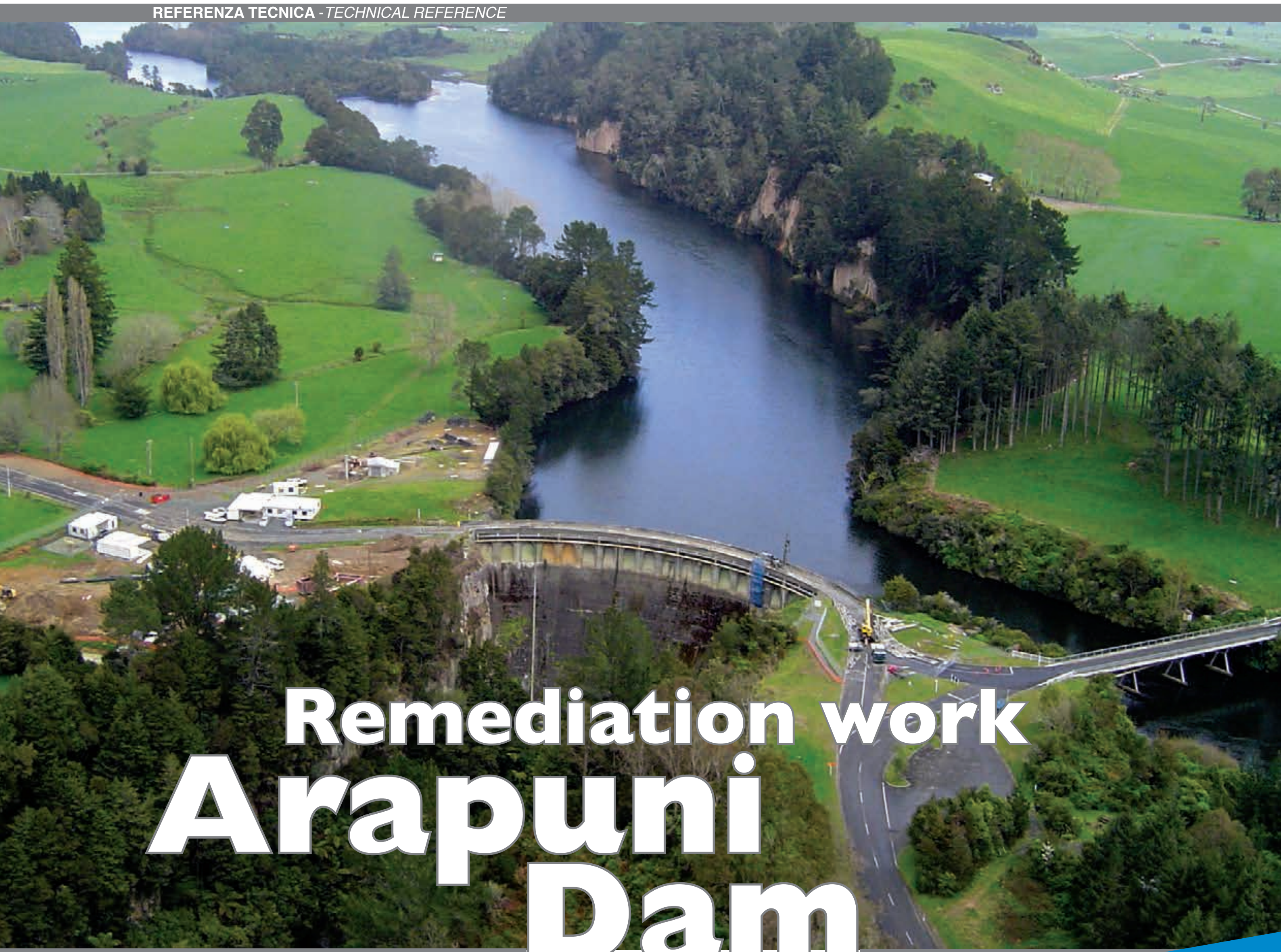


Remediation work Arapuni Dam

Waikato, New Zealand

Diaframmi
Cut-off Walls

Cliente : *Owner:*	Mighty River Power
Contrattista principale : *Main Contractor :*	**Alliance Trevi - Brian Perry Civil Eng. - Mighy River Power**
Durata dei lavori : *Duration of works:*	**2005 - 2007**

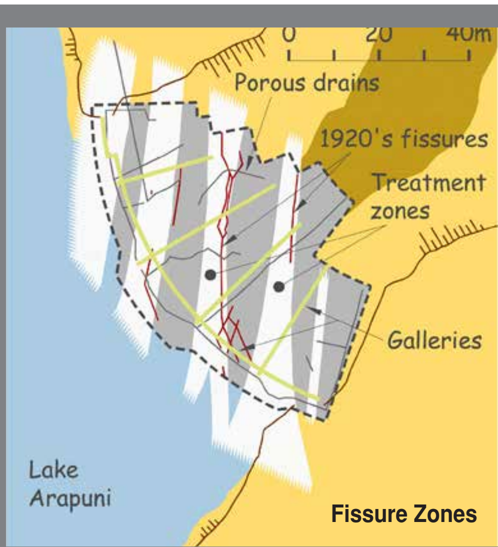
Introduction

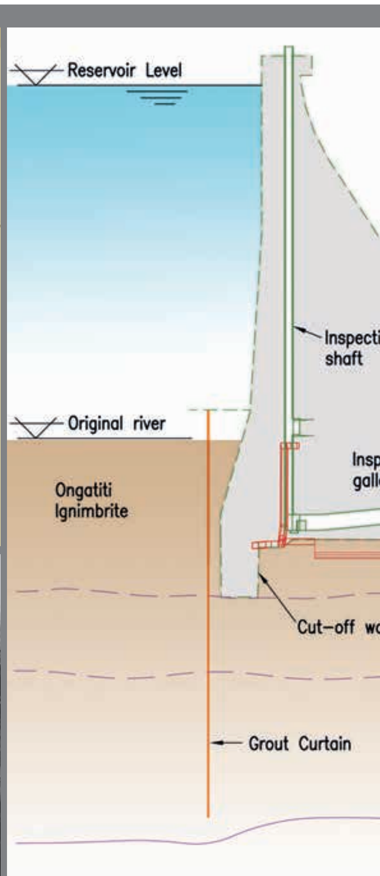
In 2007 Trevi completed the construction of a 90 m deep secant pile cut-off wall to intersect fissures in the rock; striving to push the envelope to improve existing technologies.

The owner and operator, Mighty River Power, had been planning this project for several years with the technical assistance of Dam Watch Services. To achieve the robust and verifiable solution required, they recognized that the development and application of unproven technology 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$20m project.

LOCATION MAP & WAIKATO RIVER CHAIN





After two years of work, early monitoring indicated that the cut-off was extremely effective.

Ground Conditions

The dam site is located in an area characterized by the **presence of multiple ignimbrite flows deriving from volcanic eruptions 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". A feature of this ignimbrite layer is the lack of regular orthogonal vertical jointing, which is often seen in ignimbrites in New Zealand. Three major sub-vertical cracks or fractures were detected during dam construction: they diagonally cross the dam footprint in an East-West direction.

A fourth set of fractures was identified in 2003 during the recent foundation investigations. These fractures extend along the full depth of Ongatiti and their width ranges from nihil up to 80 mm. The fractures relate to ignimbrite cooling after emplacement and are not caused by tectonic phenomena. Clay infill is generally present where the fracture opened at the time of emplacement. The fracture infill is Nontronite, an iron-rich smectite clay with a very high moisture content and very low shear strength.

Beneath the Ongatiti Ignimbrite, about 40 m below the base of the concrete dam, older ignimbrite deposits - identified as Pre-Ongatiti for this project - are encountered.

Background

Arapuni Dam is a 64 m high curved concrete gravity dam, with 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 key original features 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 constructed 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. This grout curtain was constructed


Dam outline
Porous drain/gallery
'Hard zone'
Ongatiti Ignimbrite
Pre Ongatiti

just upstream of the dam and cut-off walls, using a single row of grout holes at 3 m centres, but it was not physically connected to the dam. At the steep gorge walls a bitumen plug was constructed and the grout curtain extended radially from the crest abutments.

There has been a history of periodic seepages, through fissures within the Ignimbrite, since the reservoir has been refilled in 1932. Observed flow rates of up to 750 litres per minute have been managed using targeted grouting works.

In 2000 a trend of increasing pressure and flow was identified and solid particles of clay and bitumen, together with lake life, were observed exiting the drainage system. Investigations by Dam Watch showed that the very weak Nontronite clay infill was eroded from within a fracture forming a 'pipe' connecting the reservoir and the dam drainage system; this was successfully grouted in 2002.

Seepage Remediation

Mighty River Power required an upgrade of the dam foundation seepage's 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. As Mighty River Power's Tom Newson says *"the project is about removing the potential for leakage"*. 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 treatment to either fill open fissures or replace erodible infill with suitable materials to form a durable barrier. If the upgrade had implied a filling of the open fissures, a grouting solution would have been appropriate. Other options included the use of high pressure water or wire-sawing to cut the rock and form a cut-off intersecting the fissures. 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. By drilling the overlapping secant piles through the fissure zones, a verifiable and durable concrete cut-off can be formed.

The huge amount of collected and processed data concerning soil conditions made Dam Watch understand that the four features are not interconnected systems. Therefore, the design envisaged four discrete cut-off walls instead of a continuous one.

The cut-off walls were located as far upstream as possible to reduce uplift pressures over the largest dam foundation area, thus providing the greatest stability enhancement.

"The early alliance workshops gave the team great focus as to the desired outcomes and associated constraints; this, coupled with the detailed planning, has served the project very well" says Nick Wharmby, Brian Perry Civil's Manager Engineering.

With mobilisation and preparatory works starting in May 2005, drilling of the 136 holes commenced in September 2005

Methodology Development

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

A core sample made from the dam concrete mixed with the 'new' concrete of the panel executed.

hole. **The guide and the drilling system were studied and built in Italy by Trevi and Soilmec**, TREVI GROUP's manufacturer of specialized equipment.

The use of a reverse circulation system with tricone bit was chosen, based on drilling accuracy and environmental grounds. Testing of the drilling system was essential, along with the development of associated methods:

a. Integrity of the non-reinforced concrete of the dam during drilling and backfilling was kept by means of anchors and straps and by reducing the rate of rise of concrete.

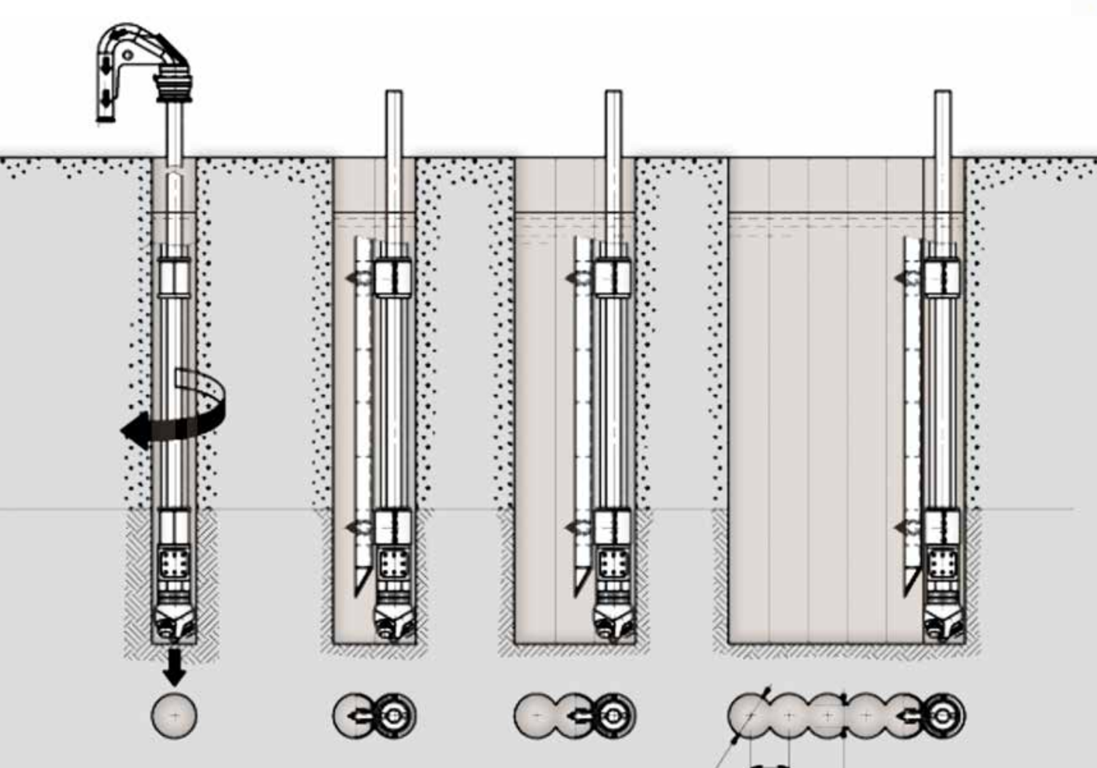
b. Working around dam features *(contraction joints, instrumentation, shafts, galleries, under-drains, etc.)* with associated works including localised filling or plating and strutting of galleries, forming under-drain connections and temporary plating across contraction joints.

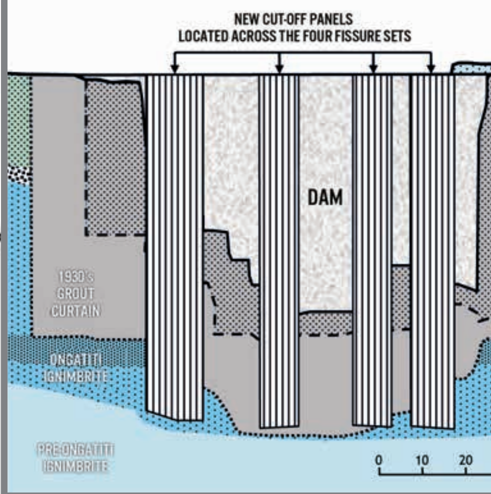
g. A properly designed concrete mix and tremie method were adopted with associated monitoring and comparison with theoretical expectations. Concrete quality was also checked by drilling down through the completed cut-off wall and testing core samples.

h. An array of pressure and seepage monitoring transducers, and a suite of "method" and contingency plans, were worked through to cover the "what if" scenarios; the dam-safety and construction personnel worked closely together.

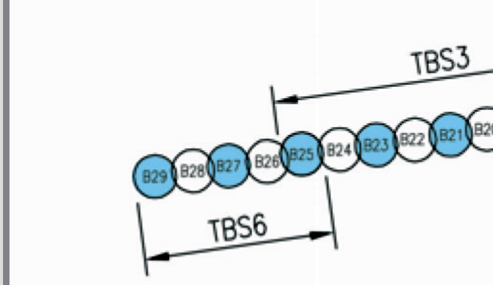
Initially, it was thought that works might be completed in a year. As it may be expected when significantly extending the existing technology, the Arapuni Dam Alliance project team had numerous challenges to overcome, such as guide frames jamming and drill strings shearing, but these led the team to develop improved guides and effective fishing tools to keep on constructing.

Sequence of Cut-off





Layout of the panel



c. The first hole in each panel was drilled at 150 mm diameter using directional drilling with real-time measuring and steering capability to obtain the accurate alignment; these were subsequently reamed out to 400 mm diameter to guide the next drilled hole. Inclinometer measurements were taken as each hole was progressed.

d. A template was developed and used to check continuity between holes together with CCTV.

e. The aim was to use a stop-end in the penultimate hole of each slot to maintain continuity between slots cast in a particular panel. However, this method was not successfully developed, so a 150 mm diameter pilot pipe was cast into the last hole and the latter was re-drilled using a reaming tool.

f. Cross-hole flow logging was carried out down each hole to make sure that, even with "managed", drainage, high flows and potential washout did not occur.

Trevi Project Manager, Marco Lucchi says *"the project has been more challenging than expected because we are drilling to depths of 90 metres and the hole has to be technically precise"* he adds *"the dam's concrete is very strong and we need more time to drill this part of the hole even if we modify the Soilmec R-312 rig hydraulic components, rotary head and drilling tools"*.

Gus Pembroke, the Brian Perry Project Engineer confirmed *"It's been a big challenge right from the start. Just when you think you're on top of things, something else will pop up and you have another problem to solve"*.

Maurizio Siepi, technical advisor for Trevi, says *"Since the early stages of the works, Trevi-Soilmec's problem-solving skills and their culture of teamwork allowed to overcome difficulties and to complete the job, in spite of project complexity"*.

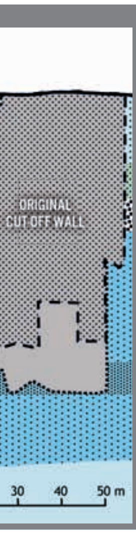
The Trevi-Brian Perry Civil crew has been working around the clock six days a week to complete the project.

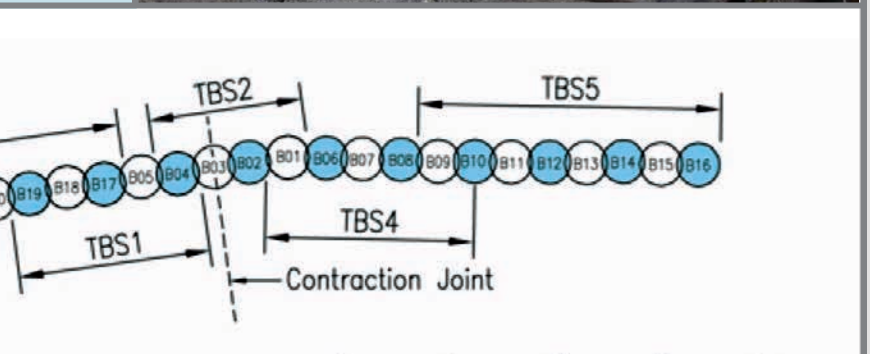
At the **New Zealand Contractors Federation 2007 Conference, the project received a Shell Environmental Excellence Merit Award** *"given the project was competing with significantly larger high profile projects this is testament to the early planning and culture of the alliance site team"* says Nick Wharmby.
The alliance has proved to be an excellent model facilitating strong technical focus and timely resolution of issues. Tom Newson from Mighty River Power is clear that an alliance was the correct choice *"For this project it was the only way to work"* he says.

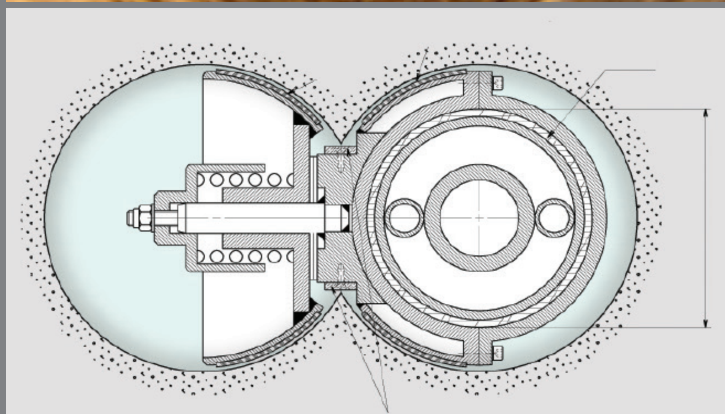
Outcome

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 international technology and experience in this field.

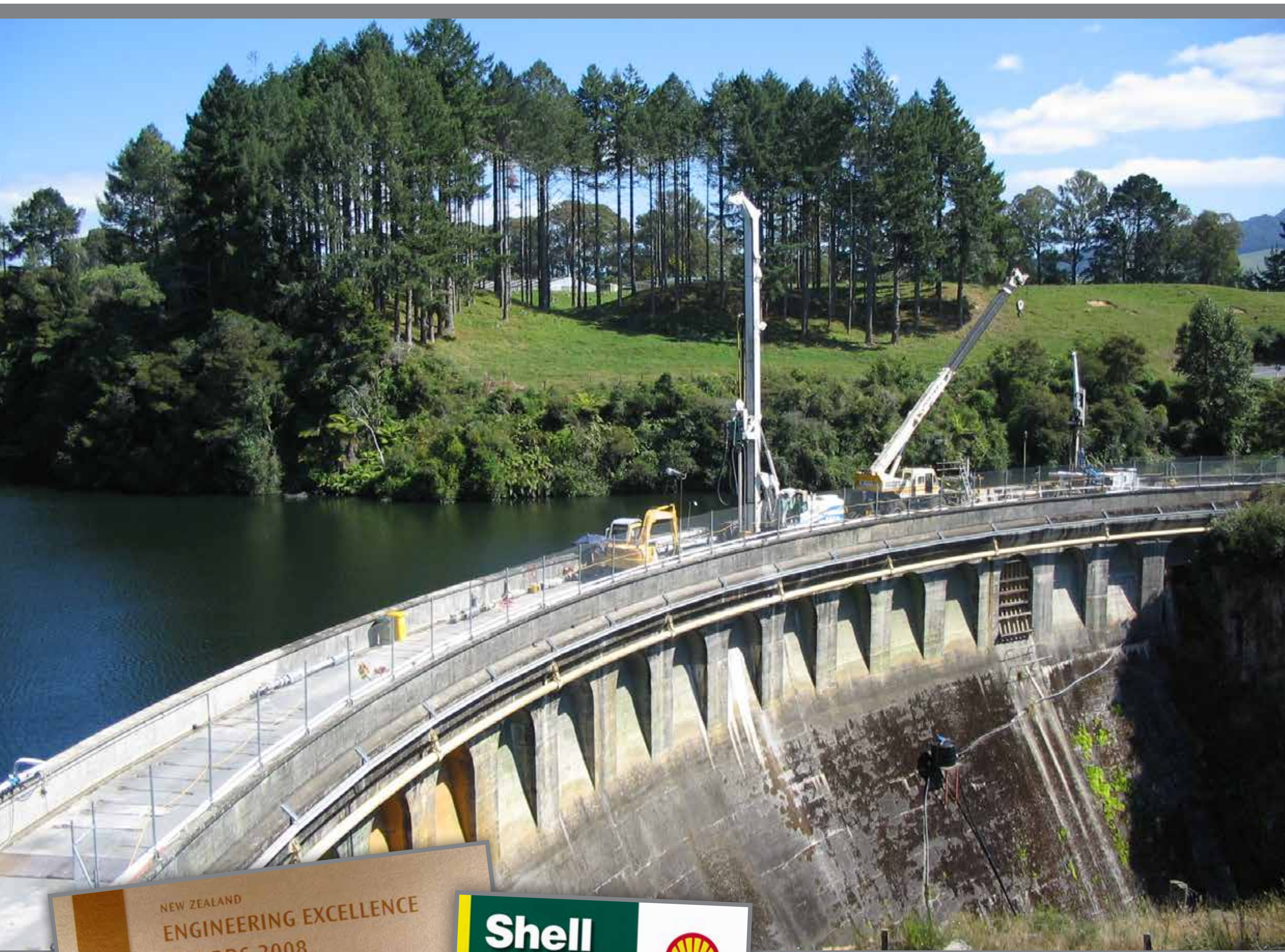
Mighty River Power's choice of an alliance procurement approach has facilitated the development of this method to enhance the integrity of Arapuni Dam foundations. This solution would not have been possible without the specific expertise and committment of all the people involved. The method of installation provides a verifiable long-term solution, aligned with treatment and project objectives.

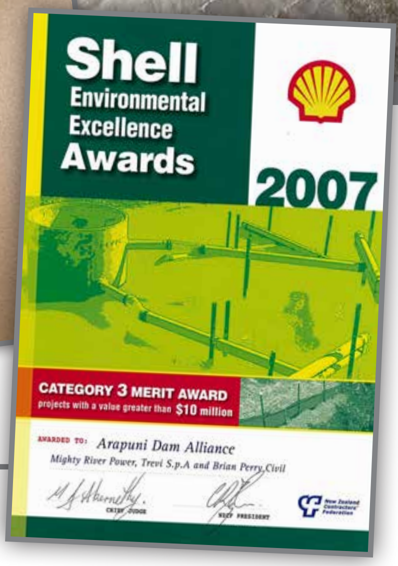






A special device attached to the drilling string.





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