Arapuni dam foundation enhancement works
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ABSTRACT
The Arapuni Dam is a 64m high curved concrete gravity structure across the Waikato River south of Hamilton, New Zealand. It was completed in 1927 to form a reservoir for the 186MW hydroelectric power station. A series of seepage events have occurred since water was first impounded. These were related to piping within, and erosion of, the Nontronite clay infilling the defects within the volcanic Ignimbrite rock foundation.

The owner of the dam required the formation of high quality, durable and verifiable cut off solution with the reservoir still in service. An international Alliance was formed to investigate options, develop them and implement the selected methodology. The paper will include the following:

- Description of the local geology
- Commentary on different solutions evaluated
- Development of the adopted solution which required the installation of 400mm diameter overlapping piles to depths of up to 85m.
- Manufacture and development of specialised plant and equipment
- Monitoring of the dam and foundation
- Construction of the cut off wall and quality control

The solution successfully implemented significantly extends the boundaries in terms of the overlapping / secant pile technology used. The outcome was the formation of a robust and verifiable cut off wall.

1 BACKGROUND
Arapuni Dam is a 64m high curved concrete gravity dam, with crest length of 94m, across the Waikato River bed. It is owned and operated by Mighty River Power Ltd, an electricity production and retailing company owned by the New Zealand Government. The dam forms the reservoir for a 186 MW hydro-electric power station, sited 1 km downstream at the end of a headrace channel that follows the left abutment. Penstock intake and spillway structures are on the headrace channel. A concrete-lined diversion tunnel runs through the right abutment around the dam, with separate gate and bulkhead shafts. The dam is shown on Figure 1.

The key original features of the dam include concrete cut-off walls and a network of porous (no-fines) concrete underdrains (Figure 1) at the dam/foundation interface. The underdrain is the main uplift control at the dam/foundation interface. The original cut off walls, as shown on Figure 2, extend to a depth of 65m below the dam crest and also into the left and right abutments of the dam. There was no grout curtain constructed during original construction. Handman (1929) discusses the dam’s construction.

In June 1930 the reservoir was completely dewatered following the development of a large crack in the headrace channel near the powerhouse. During the following two year period, while the headrace channel 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 (Furkett, 1934). The grout curtain was a single row cement curtain with mostly vertical grout holes at 3m centres. It was constructed just upstream of the dam and cut-off walls but was not physically connected to the dam. At the steep gorge walls a bitumen plug was constructed between the dam and the gorge wall, and the grout curtain extended radially from the crest abutments. Figure 2 shows the extent of the grout curtain and original dam cut off walls.
2 GEOLOGICAL SETTING

The dam site is in an area of multiple ignimbrite flows from volcanic eruptions over the last 2 million years. Details of the ignimbrite deposits at the dam site are shown on Figure 2.

Two ignimbrite units form the gorge walls. The younger Mananui Ignimbrite is present as the 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 40-50m thick sheet of Ongatiti Ignimbrite, a point-welded tuff. The upper part of the unit is very weak, with unconfined compressive strength of between 2 and 6 MPa, while below the original dam cut-off wall the Ongatiti is considerably stronger (up to 28MPa) and identified as the “hard zone” (Figure 2). A feature of this ignimbrite sheet is the lack of regular orthogonal vertical jointing often seen in ignimbrites in New Zealand. Three major sub-vertical cracks or fractures were identified during dam construction diagonally crossing the dam footprint in an East-West orientation. A fourth set of fractures was identified in 2003 during the recent foundation investigations. These fractures extend for the full depth of Ongatiti and vary in aperture from closed up to 80mm. The fractures relate to cooling of the ignimbrite after emplacement and are not tectonic in origin. Clay infill is generally present where the fracture opened around 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. This very weak clay is potentially easily erodible under pressure. Where infill is not present in fractures seepage pressures, correlating to reservoir level, are present in the open joints under the dam.

Beneath the Ongatiti Ignimbrite, about 40m below the base of the concrete dam, are older ignimbrite deposits, identified as Pre-Ongatiti for this project.
At interfaces between ignimbrite sheets there tends to be unwelded material, either airfall tephras or unwelded ignimbrite. The most extensive interface deposit is between the Ahuroa and Ongatiti ignimbrite units, known as Powerhouse Sediments, with a thickness of 4 to 8m.

3 SEEPAGE HISTORY

There has been a history of periodic seepages, through fissures within the Ignimbrite, since the reservoir was refilled in 1932. Observed flows 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, was observed exiting the drainage system. Investigations by Amos et al (2003a) showed that Nontronite infill had been eroded from within a fracture forming a 'pipe' connecting the reservoir and the dam drainage system. The pipe was successfully grouted in 2002 (Amos et al, 2003b).

4 LONG TERM SEEPAGE CONTROL WORKS

Following further investigation of fractures and seepage conditions in the dam foundation, Mighty River Power implemented an upgrade of the dam foundation seepage control measures where either of the following was present:

a) Highly erodible joint infill vulnerable to piping erosion.

b) Near-lake pressure in areas under the dam due to open fractures hydraulically connected to the reservoir.

The aim of the upgrade was to reduce the risk of further piping incidents to an extremely low likelihood and severity level and to control high pressures under the dam. Furthermore, the objective was set to complete the remediation with no interruption to power station operations (i.e. maintain the reservoir at normal operating levels). Four fissure sets were identified that required treatment to either fill open fissures or replace erodable infill with suitable materials to form a durable barrier.

4.1 Option selection

Numerous options were considered for installing the upgraded cut off barrier and trials were performed using various technologies, such as the use of high pressure water and air jets to cut rock. However, the primary difficulty with all the grouting methods was assessing whether the soft infill material had been removed or where the grout had actually hardened; verification of the
barrier was problematic. Final option assessment and selection was by the owner (Mighty River Power), designer (Damwatch Services) and constructors (Trevi SpA and Brian Perry Civil Ltd) in a formal alliance structure. The selection of the secant pile methodology was based upon a risk framework that considered achieving the technical objectives, constructability, cost and the safety of the dam during construction.

As shown above in Figure 3, remedial works specifically targeted each of the four sets of identified vertical fractures and treat the open or infilled joint by removing infill and replacing the joint material with grout or concrete. This created stable long lasting barriers across each of the four fissure sets. The cut-off walls were located as far upstream as possible to reduce uplift pressures over the largest dam foundation area and thus provide the greatest stability enhancement.

4.2 Methodology development

The basic methodology adopted comprised the construction of 400mm diameter secant piles at 350mm diameter centres to depths of almost 90m from the dam crest. To provide the required cut-off, the critical factor was to maintain and verify the overlap of the piles. A drilling accuracy or verticality better than 1 in 3600 would be required to ensure adjacent piles overlap; using conventional piling equipment 1 in 200 which is considered difficult to achieve. Improved accuracy could be achieved with directional drilling. However, drilling partially in dam concrete or soft Ignimbrite and recently placed concrete was considered as problematic as the verification process. The solution was the use of a guide attached to the drill string which located in the previously drilled hole.

The guide and drilling system was built in Italy. The use of a reverse circulation system with tricone bit was selected on drilling accuracy and environmental grounds. Testing of the drilling system was essential along with the development of associated detailed methodology such as:

4.2.1 Maintaining the integrity of the face of the dam. The dam is un-reinforced and, with the slots drilled as close as 1m from the face, it was necessary to install reinforcing anchors and propping straps to withstand drilling fluid and concrete pressures. The concreting procedure was developed to limit the rate of rise of fluid concrete within the upper portion of the dam.

4.2.2 Working around dam features. The alignment of the piles was adjusted to avoid clashes with contraction joints, installed instrumentation, access shafts & galleries and under-drains where possible. Preparatory works included localised filling or plating and strutting of galleries, forming under-drain connections and temporary plating across contraction joints.
4.2.3 As-built location of all holes. Inclinometer measurements were taken as each hole was progressed. In each panel at least the first hole was drilled at 150mm diameter using directional drilling with real-time steering to obtain the accurate alignment; these were subsequently reamed out and the alignment re-checked using the down hole inclinometer.

4.2.4 Continuity between holes. The methodology effectively guarantees the continuity between holes but at the completion of a slot a template was used to verify the required cut-off thickness had been formed. CCTV was also used.

4.2.5 Continuity between slots cast in a particular panel. This is the only location where continuity between adjacent piles can not be physically verified. The initial intention was to install a stop-end in the penultimate hole that would serve to prevent the concrete flowing into the end hole. However, over sized holes in the rock prevented an adequate seal so a simple 150mm diameter pilot pipe was cast into the last hole and this hole re-drilled using a reaming tool. Visual verification of the continuity is achieved using a CCTV camera once the drilling in the adjacent slot has been completed.

4.2.6 Ensuring good quality concrete backfill. As part of the pre-pour inspection flow logging in the slot was carried out down each hole location to ensure high fissure flows were not present. A well designed concrete mix and tremie methodology was adopted with associated monitoring and comparison with theoretical expectations. Concrete quality was also verified by using a CCTV camera and testing core samples extracted by drilling down through the completed cut-off wall.

4.2.7 Dam safety. The methodology was developed with the dam safety issues at the forefront. 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 work closely together. The monitoring of the dam foundation is documented by Amos et al 2007.

4.3 Construction

With the project being undertaken by an alliance, key result areas (KRA) were determined by the Client (Mighty River Power) and commercial participants were aligned with these. Incentives were defined for the KRAs of cost, quality and sustainability based upon exceeding minimum conditions of satisfaction (MCOS). Given the nature of the site, its location next to a key resource for many in the Waikato region and Mighty River Power’s high reputation in the community the sustainability KRA which included stakeholder and environmental factors was highly appropriate. As a result the construction team afforded considerable attention to planning and installing the traffic detour, site compound and drilling fluid/cuttings treatment circulation set up to minimise the potential for contamination of the local and wider environment. Furthermore, proactive communication with stakeholders was carried out to minimise the impact of the works and facilitate smooth operation.
As would be expected when significantly extending existing technology, the project team had numerous challenges to overcome such as guide frames jamming and drill strings shearing but these have resulted in the team developing improved guides and effective fishing tools to progress construction. The Alliance has proven to be an excellent model facilitating strong technical focus and timely resolution of issues.

Figure 5: Working on the congested dam crest

5 CONCLUSION

The construction of a concrete cut-off wall under a dam whilst it is in service is uncommon. Also the construction of overlapping / secant piles to such depths represents a significant extension to international technology and experience in this area.

An alliance approach has facilitated the development of this methodology to enhance the foundation under the Arapuni Dam for the owner Mighty River Power. The solution would not have been possible without the specific expertise and focus to find solutions of all those involved. The method of installation provides a verifiable long term solution aligned with treatment and project objectives.

REFERENCES


