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CONSTRUCTION OF TEKAPO A NEW INTAKE GATE AND SHAFT

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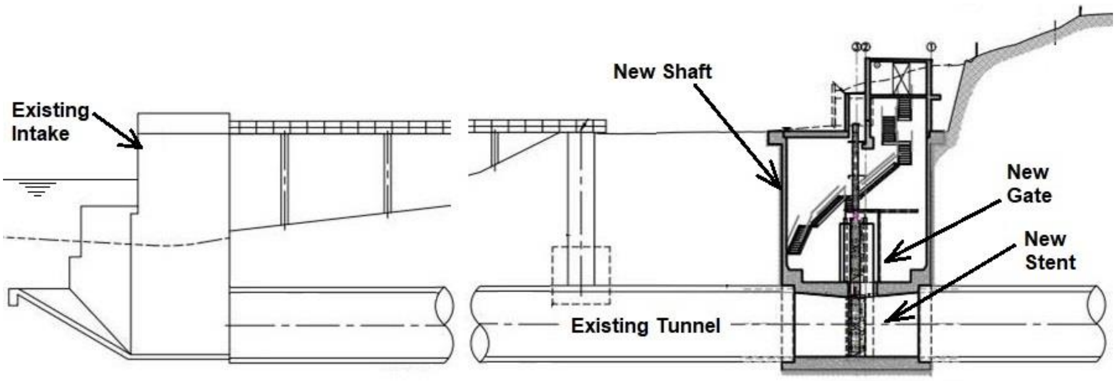
SUMMARY

In October 2018, Downer was awarded a $15.3M contract by Genesis Energy for the supply, construct, and commissioning of the new Intake Gate for Tekapo A Power Station. The new gated water intake will allow Genesis Energy to stop the flow of water to Tekapo A Power Station in an emergency. Water from Lake Tekapo flows through the existing 1.6km long tunnel to the Tekapo-Pukaki canal and to the power stations on the rest of the Waitaki scheme.

The work involved building a shaft extending down to the tunnel, exposing and cutting into the tunnel, fitting a steel "stent" section into the tunnel and installing the gate with its guide slots and hydraulic ram. Genesis required works to be carried out between specific time periods so that there would be minimal disruption to the generation of power.



Downer and Parfitt Construction Ltd worked collaboratively with the client, Genesis Energy, and the design consultants, AECOM to overcome challenging conditions and develop innovations which reduced risks and saved time, ensuring that the Client's expectations were met.

Some of the challenges and construction smarts included:

- Innovative construction methods for the concrete shaft and roof
- changes to the concept of the "stent"
- specialist concrete mix designs
- unique risks including the remote nature of the site, cold temperatures, confined space tunnel work, and working through the COVID-19 lockdowns of 2020
- fabrication and handling of very large, precision engineered components.

All works were completed on time and to the revised budget of $17.6M, with no impact on power generation activities outside of the agreed shutdown periods.

Key words: concrete shaft, shotcrete, concrete pour, power station, outage, tunnel, excavation

1. INTRODUCTION

Five years from planning to completion, the project had to overcome a number of unique engineering challenges, including how to integrate modern gate technology into infrastructure and tunnels originally designed and built in the 1940s. This included developing an innovative permanent stent option for the existing tunnel to allow flows during construction and a methodology to construct the shaft in layers, expediting this critical piece of work.

Construction of the permanent stent and concrete shaft was completed within the constraints of two non-negotiable shutdowns or "outages" of 17 weeks and 8 weeks respectively, plus a third outage for final install and commissioning. The shaft required excavation to a depth of 21m, just 50m from the shore of the lake, to a depth of almost 15m below lake level, with over 4,000 tonnes of concrete poured in this sensitive environment.

Figure 1: A project of national significance, Tekapo A Intake Gate project was completed on time and under budget, ensuring continued powering of over 125,000 Kiwi homes

Given the depth of the existing tunnel and shaft, this work needed to be delivered under the Health and Safety at Work (Mining Operations and Quarrying Operations) Regulations 2016, to manage these critical risks.

Genesis wisely engaged Cromwell local Les Topping as Engineer's Representative and Joe Edwards as Engineer to the Contract.

1.1 Shaft innovations

To closely align the works with Genesis' programme expectations, Downer and key subcontract partner, Parfitt, collaboratively developed and proposed an alternative approach for the construction of the shaft.

The original solution detailed at tender time for the shaft was to construct the permanent shaft walls "top-down" in 1.5m sections, using formwork and in-situ poured concrete. This had the advantage of minimising temporary retaining works but had programme, cost and potential quality implications. The joins between concrete pours for this method of construction pose a risk of leakage and each section would be slow and difficult to build effectively.

The alternative approach was to dig and temporarily support the shaft using shotcrete and soil nails all the way to the base followed by "bottom-up" permanent construction. This method reduced the timeframe for each 1.5m section from two weeks to just one week, allowing the Client's deadlines to be met. The choice of shotcrete for time critical activities also reduced delivery and temperature risks.

1.2 Stent innovations

For the original sequence, all permanent works were to be constructed prior to the opening of the tunnel for generation at the end of the planned first (17 week) outage. Completing this quantum of work in a relatively short time period created programme risk and so an intermediate stage was developed which utilised a "stent" installed at the base of the shaft to allow full generation to occur while the permanent works were completed.

Subsequently, all works were completed on time and to budget with no additional impact on power generation activities.

1.3 Construction Risks Managed

Access to Tekapo via State Highway 8 posed some risk, as any incidents on either the Tekapo to Fairlie or Tekapo to Twizel portions of the road could effectively cut off access, with no other routes available on either side of the township. The COVID-19 lockdowns of 2020 created additional challenges on top of the remoteness of the site, with transportation and supply chains significantly affected. Careful planning was required to manage these risks, along with advance ordering and stockpiling of materials on site.

Figure 2: Extreme temperatures were a risk to concrete quality

Isolation was an issue to consider for the time critical shaft construction and, accordingly, the decision for Parfitt to self-perform most activities was made. This allowed accommodation to be booked out and a great project culture to be developed amongst the close-knit project team led by Project Manager, Alex Mowe and Site Supervisor, Don Hayward.

Local general and precision engineers Gibson Brothers in Fairlie were called upon frequently to make urgent repairs to keep the job going.

All reinforcing was supplied and placed by Complete Reinforcing, Christchurch. All concrete was supplied by Kiwi Concrete, Twizel. In-situ concrete was placed using a skip and shotcrete was fed from a trailer pump.

To mitigate the potential risk of voids and water erosion, a 60MPa self-compacting mix was developed for the gate slot secondary concrete. Kuniseal hydrophilic sealants and a waterproofing admixture were used in all in-situ concrete pours.

Some winter concreting was required but fortunately, during this time, the temperature in the tunnel and shaft was slightly higher inside than the ambient outside temperature. This helped to mitigate the risks posed by cold temperatures.

A full scale heat of hydration analysis was completed for the base slab staging pours.

All quality requirements were met despite the cold weather and remote site.

2. CONSTRUCTION

2.1 Soil Nailed Retaining Wall

To facilitate a clear, level construction area, a 6m high retaining wall was constructed, containing 100 x 5.5m long soil nails and shotcrete. These works were completed 22 days ahead of programme. This work also provided an opportunity for the design and construction team to refine procedures for installing the soil nails and shotcrete for the shaft leading down to the tunnel.

Figure 3: Completion of 6m high retaining wall

2.2 Excavating the Shaft

A 14m diameter circular shaft with reinforced concrete walls was required to access the tunnel and to house the new gate.

An early innovation of Downer and Parfitt was to temporarily support the sides using shotcrete and soil nails so that the excavation could proceed at pace. Construction of the 400mm thick reinforced concrete walls could then follow on in parallel with other work since it would no longer be on the critical path.

Temporary access to the bottom of the shaft was via a “hanging” Layher scaffold, with new modules added underneath the tower at each lift.

Excavation was carried out by a 13t zero tail swing excavator, and removed by filling a kibble skip, which was lifted in and out of the shaft with a 120t crane. Fill was carted 3km off site and stored for use later in the project as backfill between the control building and temporary retaining wall.

Excavation of the shaft and the removal of material was a challenge, particularly as the depth increased. Key communication protocols were developed for removal of each kibble. Up to 20 lifts of 15t each were made in a single day, and daily briefings were held with the team to ensure each days lifting was properly planned and reviewed.

Protocols included:

- Top and bottom dogmen for controlling all lifts
- Top dogmen stationed in a crow’s nest on the edge of the shaft to gain full view
- Bottom dogmen controlling lifts leaving the shaft base and rigorously handing over to the top dogmen at the top of the shaft for clearing the shaft and landing the kibble topside
- The controlling dogman always having direct line-of-sight visibility
- All personnel down in the shaft stationed in a refuge area or ‘safe-zone’ during all lifts, including the excavator operator
- Careful filling of the kibble to avoid overloading or spills.

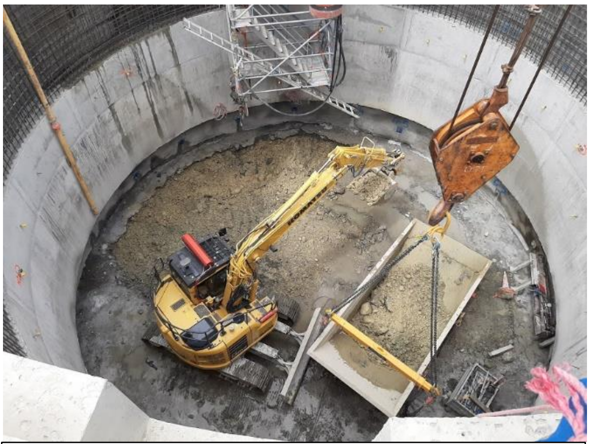


Figure 4: Excavation of the shaft

The glacial till material could be excavated to a vertical face but was prone to fretting and spalling. To prevent dropouts during drilling, mesh was placed and shotcrete was sprayed on the newly exposed face prior to drilling the soil nails. Shotcrete was delivered using a Putzmiester BSA1002 piston pump and a 4” hard line reduced down to a 2” soft line at the base of the shaft. A knife gate valve was always positioned at the base of the shaft. Shotcrete was originally specified as 30MPa and this was successful for the retaining wall and upper shaft, however as depth progressed, blockages were more common. The mix design was increased to 40MPa which provided more fines and assisted pumping. With the batching plant up to an hour away and the shotcrete process taking 30 minutes per truck, all parties needed to work together. It was important that the drivers continuously spun their bowls and that slump tests were taken before and during truck discharge. Superplasticiser was on hand to increase the slump when required.

At each excavation stage, 21 hollow bar soil nails were installed using a neat cement grout flush with a Hutte HBR504 drill rig and Krupp drifter. The rig was well sized for the job, having just enough space to fit in the 14m diameter excavation while still having ample power to maintain productivity. Generally, all 21 nails could be installed in a single shift. All grout was mixed topside and pumped down in a 1” line to the drill rig. A valve was available at the rig to help control flow. All pull-out tests exceeded requirements with sacrificial tests not being able to move the bar before yield was approached, indicating good bond. Soil nail lengths were reduced following sacrificial testing. Generally, grout volumes per nail were as expected except for nails on the lake side of the shaft which occasionally hit voids and often required up to 20-30 bags to maintain flush during and after drilling. Historical photos indicated that this was an area disturbed by excavation and backfill activities during the 1950’s tunnel portal works. Shaft temporary works design was completed by Soil and Rock and A O'Sullivan and Associates, and included modelling of each permanent and temporary construction phase.

Communication between topside and shaft teams was via ear-muff mounted radio. Noise from the ventilation fan, drill rig engine, shotcrete operation and drifter operation in the shaft was deafening at times threatening to turn simple tasks or requests into safety hazards.

Excavation, shotcrete, and soil nail works were constructed down to a level 4m above the tunnel crown while the tunnel was operational and pressurised. No further work was carried out until the tunnel was emptied of water. This ensured that the worst-case internal water pressure did not overcome the overburden weight leading to potential tunnel failure. This analysis was completed by AECOM tunnel engineers in Sydney.

Progress to this level above the tunnel was faster than forecast, providing a window to commence the permanent walls before the first outage period. This was a valuable programming advantage which allowed a portion of the shaft walls, 3.6m high, to be constructed early. However, this also meant that this 180t ring of concrete would be undermined when excavation was recommenced. To ensure that there was no possibility of this ring sliding down the shaft, temporary support was required. The desirable solution was to "hang" the wall from the ring beam above, using the reinforcing steel, but that meant that all of the laps in the reinforcing would have to be positively tied together (and welding was not allowed.) Appropriately sized "bulldog" grips were sourced, but no load data was available for bulldog grips holding reinforcing steel bars, so testing was carried out by Holmes Solutions. A simple and effective temporary support design was developed using these test results.

Figure 5: View inside the existing tunnel

2.3 Opening up the Tunnel

The tunnel was dewatered (drained) at the commencement of the first planned maintenance outage. This relieved the internal pressures in the tunnel and allowed shaft excavation to continue.

The tunnel was never designed to be exposed from above so a cautious approach was taken. AECOM carried out a review of tunnel stability and certain loading restrictions were imposed. There was great conjecture on whether the tunnel segment bolts had been left in place during original tunnel construction in the 1940's. Such bolts may have been rare, and if they had been removed, this would have made a difference to the restrictions. The segments were conservatively assumed to be unbolted.

To access the tunnel, a 'letterbox' opening was cut into the crown of tunnel. This opening was restricted to 4.2m in width. This size determined maximum size of liner plates (and the amount of welding). A wire saw was used to cut a neat hole in the tunnel crown. (Bolts were present!) The existing tunnel, now 70 years old was found to be in excellent condition, and very close to dimensional expectations.

The next stage was to install the steel liners. These liners were critical to continued progress – they effectively extended the length of the stent, upstream and downstream, and were doweled, grouted and sealed to the tunnel walls to provide additional strength to the existing tunnel in these critical areas. All this work had to be done through the relatively small 'letterbox' opening so that the stability of the tunnel was not compromised.

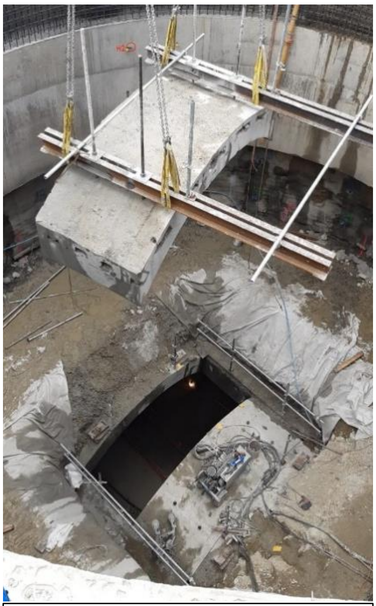


Figure 6: Removal of tunnel crown for access

The tunnel liners were manufactured in halves, totalling four curved sections upstream and four curved sections downstream. The restriction in 'letterbox' size provided a challenge to install the liners in a short time. The bottom half was lowered in to the tunnel on its side (3m wide), rotated to horizontal within the tunnel and slid on skids using a snatch block and the crane winch up into the tunnel, away from the opening. The top section was then lowered in and rotated to horizontal inside the tunnel, before the bottom half was then pulled back beneath the top half (using a tirfor) and secured. The liner set was then winched along the tunnel and into position. Comprehensive lifting and rigging plans were prepared well in advance to ensure this lifting could all be done safely without damaging the liner sections. A trial tunnel was set up at the Parfitt fabrication workshop to check the method. All eight liner rings were installed over a one-day period using this very efficient method. The liners were levelled, doweled, welded, grouted and painted in place.

Figure 7: Tunnel liners arriving on site

The tunnel circumference was cut using a 3m diameter wall saw blade by Concut Christchurch from inside the tunnel. This provided an accurate cut face in the tunnel, upstream and downstream at the location of the future stent.

A simple and safe working platform was created in the tunnel by filling the tunnel with gravel. Two bulkheads were constructed, one upstream and one downstream to confine the gravel platform and this allowed construction of the lower part of the shaft to continue using the same proven method used for the upper part of the shaft. The gravel platform was progressively lowered as the remaining stages of the shaft were constructed. During each stage, part of the tunnel was demolished using a breaker on the excavator until finally the invert was reached, some 21m below ground level.

2.4 Installing the Stent

Figure 8: Fabrication of stent underway in vertical position

To achieve programme and complete works within the required shutdown periods, the team were required to install a steel “stent” to carry water beneath the shaft construction area. Initially designed as a temporary measure, the original stent was smaller in diameter than the tunnel itself, which would have reduced the flow of water and limited power generation. Working with the client and designer, Downer offered an alternative:

- support the tunnel either side of the shaft construction area with permanent tunnel liners
- install a permanent steel stent that met the diameter of the original tunnel and provided a slot for the new gate.

The stent was made of 8mm skin plates and a series of fabricated T sections of web and flange at 300mm centres. It transitioned from an upstream egg-shaped tunnel to the rectangular gate and back to the downstream egg-shaped tunnel, making for quite a complex, fully welded geometrical structure more akin to an ocean going ship than a civil structure. The 40t stent was fabricated and painted at the Parfitt workshop in a vertical orientation to minimise jig costs (a set of 120t crane booms in the vertical position were used). Vulcan supplied, cut and tip folded all plate. Each stent was rotated to horizontal and transport was via an ultra-low bed trailer designed for tank transport and operated by Jackson Heavy Haulage.

Figure 9: Installing the Stent in two halves

With the liners in place, and the existing tunnel removed within the shaft footprint, the two stent halves could be lowered into place. The two sections were lifted in one at a time. The cylindrical ends were butted against the sawcut faces of the tunnel with the square ends meeting in the centre of the shaft. Placing the second section was a challenge, with extremely tight tolerances at either end. There was only 100mm of space between the stent piece and the stair tower, and a similar distance between each section once these were actually in place. Although challenging, each section was successfully slotted into place and connected using a combination of temporary and permanent sealing plates. To ensure stability of the stent during full tunnel operation (6m diameter of water), 1.5m of concrete was poured at the base of the shaft to encase the invert of the stent. Pour heights were limited due to the concrete pressures acting on the stent.

With the tunnel liners and stent fitted and tightly sealed against the slightly oval tunnel circumference, water could again flow through the tunnel. Works continued above in the shaft and generation of power resumed. The permanent stent option also meant that further works were not required on completion of the project to re-enter the tunnel and remove temporary measures.

Robert Bird Associates completed heat of hydration analyses which modelled the internal tunnel water temperature, the ground temperature, the height of each pour stage and the time between pours to ensure critical temperature differentials did not occur in the 1000m3 concrete raft at the base of the shaft. AECOM confirmed a slight reduction on concrete strength to 25MPa could be employed in the raft concrete to assist with temperature control.

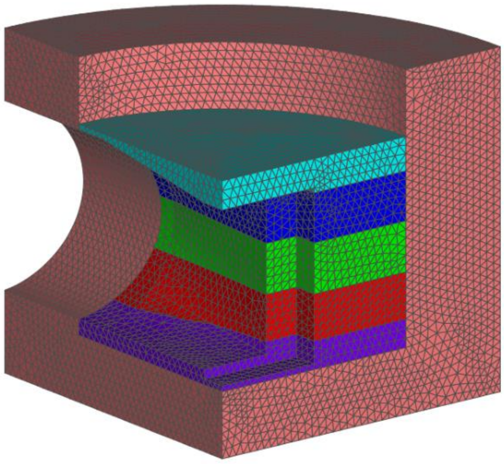


Figure 10: Heat of hydration analysis staging

Above the shaft base slab, a Doka circular formwork system was used to form the permanent shaft walls. Generally, 1.2m lifts were chosen for the pour height. A modular access platform was fixed to the formwork for each pour and boom lifts and the crane were used to jump the forms up to the next lift or to complete any remedials. A one-week turnaround was achieved.

2.5 Shaft Roof and Control Room.

The roof slab over the shaft was originally designed and detailed as fully in-situ. While possibly being simpler to detail, an in-situ slab is slow and requires substantial falsework, so the project team developed a precast + topping alternative. This method offered programming advantages but there were still challenges to overcome such as large spans, loads relating to mobile crane outriggers, access provisions and the not insignificant weight of the control room structure.

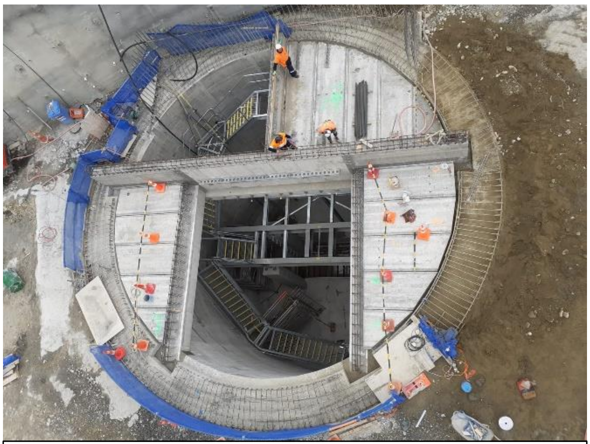


Figure 11: Precast roof layout

To meet these requirements a post tensioned beam, hollow core slab and in-situ topping slab option was chosen with the result that all falsework and temporary propping for the roof was eliminated.

The largest lift was the 45t “T beam” which was the main spanning member and was 2.4m high (also being the lower part of the control building walls). Beams and roof elements were made at the Parfitt precast yard in Christchurch and transported to site by Smith Crane and Construction.

Figure 12: Control room structure

The control room was a “Ministry of Works” style, fully in-situ concrete bunker. Doka Frami formwork was used to form wall, floor and roof elements. A horizontal rough sawn timber finish was provided in keeping with the surrounding concrete work.

2.6 Installing the Gate

The gate was manufactured in two halves – a 32t lower half and a 17t upper half, and fabrication was an exacting task. Installation tolerances were extremely tight and placing the gate was challenging.

Each section was lifted into place in the pre-formed metal slot with just 5mm of free space each side. Care was needed to avoid damaging the all-important gate seals and seal faces. Installation was successfully achieved in just nine hours, a testament to the good planning, precision engineering and the quality assurance carried out in the manufacture of all of the static and moving parts.

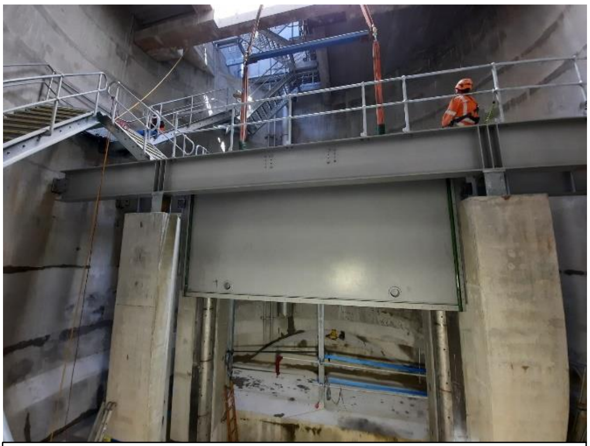


Figure 13: Gate installation

2.7 Next-level' quality control

With key elements of work needing to align to very tight tolerances (e.g. the prefabricated sections of the gate), quality was regularly and thoroughly monitored.

A key quality consideration was the temperature during concrete pours, especially in winter. Weather forecasts were reviewed against concrete/shotcrete pour schedules to align pours and volumes with the warmer parts of the day.

The concrete used to encase the plates for the gate runners was specified as 60MPa and the space for placing it was either very tight, or inaccessible. In some places it was so tight that the use of normal compaction equipment was not possible. The high strength concrete with its high cement content and short workability period further exacerbated the problem.

To address these challenges, a high strength, self-compacting mix was developed with Kiwi Concrete that would give sufficient time to place, whilst also taking into account the one-hour delivery time to site from Twizel. Trial pours were conducted by setting up a typical pour lift on site and placing the mix to check if it would fill all of the voids. The trials were successful.

Farra Engineering Ltd (Dunedin) were chosen to manufacture the gate and the associated components since they had the ability to machine these large and complex fabrications. The stainless steel plates on which the gate wheels would run, and to which the seals would come into contact, had to be machined to exacting tolerances. For example, the bottom seal plate was checked against a reference straight edge for a flatness deviation of no more than 0.5mm, and the gate had to seal such that there was no more than five litres of water per second leaking when it was closed. On completion, the leakage rate was measured and found to be a minimal one litre per minute.

All concrete and grout testing was carried out by Downer's own ISO accredited Road Science laboratory.

Three external audits were undertaken by Rileys (working for Environment Canterbury) as part of the Building Consent requirements.

2.8 Protecting Lake Tekapo

There were a number of environmental challenges on the project, given its location on the shores of the pristine Lake Tekapo. Storm water and surface runoff were carefully managed by a combination of silt fences, drainage channels, soak pits and the natural permeable nature of the glacial till ground. Lined skips were used for collecting wash-down water from concrete trucks.

Dewatering was flagged as a big risk item given that all discharge into the lake had to meet critical sediment requirements. Four wells were drilled around the perimeter of the shaft using the Hutte rig used for soil nailing. Each had a submersible pump with high and low alarms and cut-out and ran 24hrs a day for the project. Care was taken to position wells away from soil nails to avoid grout ingress into the dewatering system.

Figure 14: Working on the shores of Lake Tekapo

Water pumped from de-watering wells was contained in sediment tanks before being discharged into soak pits or other prescribed outlets and regular monitoring of water quality confirmed that PH limits were never exceeded.

Figure 15: Successful completion was second only to the view.

CONCLUSIONS

In February 2021, after 18 months of construction, the Tekapo Intake Gate Project was completed on time and on budget, protecting one of the South Island's key hydro power schemes from the risk of uncontrolled water discharge due to significant earthquakes.

Downer NZ and Parfitt Construction Ltd worked collaboratively with Genesis and designers AECOM, to overcome significant engineering challenges and develop engineering smarts that led to a successful outcome:

- Innovative construction methods were developed for the concrete shaft and roof which saved time
- Changes to the concept of the "stent" added value and reduced risk
- Specialist concrete mix designs contributed to a quality outcome
- Unique risks were managed including site remoteness, cold temperatures, confined space tunnel work, and working through the COVID lockdowns of 2020
- Very large, precision engineered components were successfully produced, installed and commissioned.

The project won the CCNZ "Category 3" award at the national conference in Wellington on 30th July, 2021.

ACKNOWLEDGEMENTS

- Genesis Energy – Client
- Les Topping and Associates (Engineer's Representative)
- Joe Edwards (Engineer to Contract)
- AECOM – consultant
- Kiwi Concrete – concrete supplier
- Farra Engineering Ltd – gate
- Queensland Hydraulics – hydraulic ram
- JLE - Electrical
- ABB - Automation