DAMMING THE DAM

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ABSTRACT

The Arapuni Dam was constructed in the 1920s, and seepage was first identified as early as 1929. There have been a number of episodes of remedial work carried out over the years. From 2005 to 2006 a long term definitive programme was carried out to prevent further seepage. The work involved pouring a curtain wall of 50m width and up to 90m deep. What made the project unique was that it was performed with a full lake and without interruption to power generation. This was done within strict environmental guidelines that allowed for nil contamination of the lake.
The project required a highly flowable concrete that remained alive for 4 hours from initial addition of water to the mix at a production facility 45 minutes from the site.

INTRODUCTION

The Waikato River, the longest in New Zealand, is located in the central North Island. Originating on the slopes of Mount Ruapehu in Tongariro National Park as the Tongariro River, it flows north through Lake Taupo and flows northwest to enter the Tasman Sea south of Auckland. The river is 425 km long. It has a gentle gradient and carries a heavy load of ash from the volcanic highlands. Major towns in its valley are Taupo, Cambridge, and Hamilton. Eight power stations built on the river between Taupo and Karapiro are a major source of hydroelectric power. The artificial lakes created by the power stations are popular boating and recreation areas. These stations and their features are listed in Table 1 below:

NAME	CURRENT CAPACITY	LAKE SIZE
Taupo Control Gates		3300km^2*
Aratiatia	84,000 kW	0.55 km^2
Ohakuri	112,000 kW	12.6 km^2
Atiamuri	84,000 kW	2.4 km^2
Whakamaru	100,000 kW	7.4 km^2
Maraetai 1	360,000 kW	4.1 km^2
Maraetai 2		
Waipapa	58,500 kW	1.6 km^2
ARAPUNI	**196,600 kW**	**9.4 km^2**
Karapiro	90,000 kW	7.7 km^2
TOTAL	1,085,100 kW	45.8 km^2

Table 1: Hydro Electric Power Stations of the Waikato River.
* Catchment area of Lake Taupo

Arapuni was the first high dam and is the oldest operating dam on the Waikato River. It was completed in 1929 and the powerhouse is protected under the Historic Places Act. Lake Arapuni is the second largest in the Waikato river system covering 9.4 km^2. It was also the first Government operated scheme on the river. Initial surveying in 1916 found an old watercourse just upstream of one of the narrowest parts of the gorge. Surveying was stopped in 1920 due to a lack of Government funds, but construction commenced in 1924. Heavy rain and the resultant floods made early work on the project slow, and a dispute between the Public Works Department and the original contractors saw the dam construction being completed by the Public Works Department. However the station was commissioned in 1929 generating from two vertical Francis turbines. The station was shut down for two years very early in its life when the seepage, that has just been stopped, was first discovered. A third generator was added in 1930 and a fourth in 1932. Four more were added in the period between 1937 and 1946. During this time the size of the powerhouse was doubled from the original. The first four turbines generate 22,500 kW each running at 214 rpm, the second four generate 26,660 kW each running at the same speed. The structure is a 64m tall concrete arch dam that is 94m long at its crest narrowing to 52m long at its base. The crest is 5.8m wide and carries road traffic between the rural areas of the King Country region and the Southern Waikato area. In 2002 a major efficiency upgrade was completed. This included mechanical, structural, electrical and environmental upgrades, ensuring that the largest single generating station on the Waikato River provides long reliable service in line with modern acceptable operational and environmental conditions. Like all the generating stations on the Waikato River the Arapuni Dam is controlled remotely from Hamilton, 60km from the dam, by the State Owned Enterprise (SOE) Mighty River Power.

In 1929 the first evidence of seepage was detected and over the years there have been various remedial works carried out. Throughout this time the seepage has had the potential to compromise power generation but has never raised any issues around the integrity of the dam. In the late 1990s plans were drawn up to seal off the seepage completely. As part of the project a large number of new sensors were added to existing monitoring equipment. This enabled a continuous check to be kept for any changes in conditions at the dam.

Figure 1: Panorama of Arapuni Dam looking upstream

THE PROJECT

The project to carry out a long term definitive programme to prevent further seepage through the friable rock came together in the early years of the 21st century. It was resolved that a construction alliance was the most likely model to produce a satisfactory outcome for all parties. The Arapuni Dam Alliance was formed, consisting of the client and asset owner Mighty River Power, Brian Perry Civil Ltd from Hamilton, a respected civil engineering contractor who has won numerous awards for their work, and Trevi S.p.A from Italy, a worldwide leader in specialist foundation engineering and drilling. Throughout the project the dam's safety and stability was monitored by Damwatch, a New Zealand company formed on the dissolution of the Electricity Corporation (another SOE) to specialise in the overseeing of dam safety in New Zealand and Australia. This company currently has contracts to ensure the ongoing safety of 35 dams.

The project in this case called for creating a curtain wall approximately 50m long and 90m deep, formed by pouring 4 panels. Extensive preliminary work was done to understand how much seepage was actually happening, including colour traces in the water and very accurate recording of water temperatures down to 0.01°C. During this investigation fissures in the rock were found to be big enough to allow the passage of snails and small fish. The upstream face of the dam was surveyed from a remote controlled mini submarine that could operate down to the bottom of the 64m tall wall. A major consideration for the project was the environmental performance. The Waikato River is the major water source for a number of towns and cities downstream of the dam, and carries considerable spiritual significance for the local Maori population associated with the river. Therefore there was zero tolerance of contamination of the water. This required Trevi to design a new reverse circulation drilling system where the cuttings are sucked out of the drill hole rather than the normal direct drilling system where the drillings are washed out of the drill hole. The strict environmental requirements also dictated the use of vegetable based drilling lubricants that were piped away from the crest of the dam for clarifying and recycling. It also meant that any residue from the concreting operations had to be contained either within the tremmie pipes, or in the dedicated truck wash down pits that were isolated from the river. The concrete was placed into each curtain using a 150mm diameter tremmie pipe. Each pour consisted of approximately 80m^3 of concrete which brought the curtain to within approximately 5m of the crest. It was left to gain strength for 3 to 4 days before being topped off. This method ensured that the dam didn't suffer from excessive internal hydraulic pressure from the highly fluid concrete. A total of approximately 2000m^3 of highly flowable concrete was supplied to the project. Due to the nature of the slot construction method there was no compaction of any of the concrete so the mix design, whilst not strictly a Self Consolidating Concrete (SCC), certainly had to perform in that manner.

THE CONCRETE

Holcim New Zealand became involved in this project very early when initially contacted by Brian Perry Civil to provide information that would enable them to carry out their project planning and likely concrete pour rate capacities. Initial discussions suggested that it was likely that concrete may be required at any time of the day or night, and could include Sunday work. With the project being relatively isolated it was important to them that there were contingency plans available to cover potential difficulties such as plant break downs or road closure issues. With plants at Cambridge and Matamata being almost equidistant from the project at 36km and a third plant at Otorohanga, a further 20km away, the project was covered from three directions. None of the plants is sophisticated and they normally service large surrounding rural areas. Cambridge Plant, the primary plant designated for the project, is a front end loader fed plant with automatic weighing for water and cement only. It has a single cement silo with a pressure pod that feeds to it to provide backup cement storage capacity. Admixtures were dispensed through flow meters, an extra being added for this project to ensure accuracy was

Figure 2: Discharging Concrete into Tremmie Funnel

maintained at all times. The concrete is mixed in trucks, not the normally recommended process for technical concretes such as required for this project. All trucks in the Holcim Waikato fleet have mixer bowls fitted, and are all checked annually for mixer efficiency as required by the NZRMCA Plant Audit Scheme. Travel time in the loaded concrete trucks was approximately 45 minutes, initially on State Highway 1, then on a good tar sealed rural road.

The specification called for a flowable concrete with an on site slump of 180mm with an allowance up to 200mm. Further, the slump was to remain at over 120mm for 4 hours from the addition of water. The mix was designed to remain alive for 3 hours after arrival at site. This was to ensure the concrete would fill the slot completely as the tremmie pipe was raised. It was this requirement that also put the hydraulic strain on the dam. There was also a requirement to hold in stock a specified anti washout admixture to be used if the flow in the bottom of the slot exceeded 4 litres/second. Our initial mix design was based on a successful SCC mix and modified for a lower workability whilst retaining the inherent cohesiveness that came from the original SCC style. The next parameter to be satisfied was the slump retention characteristic called for. After discussion with Sika (NZ) Ltd we opted to carry out a full size trial at a dose rate of 750ml/100kg cement. This was in conjunction with Sika's Viscocrete 5-500 superplasticiser at 750ml/100kg cement. There is a limited range of cements available in New Zealand, and we chose to use GP which is similar to ASTM C 150 Type 1 cement with an ISO-CEN strength of approximately 62.5MPa. This was done to enable the plant to continue to service our everyday clients. It also ensured that in the case of having to swap plants there would be no holdups due to different cements being used at the other plants, all of which have only one cement silo. To assist with the cohesiveness, and aid flowability, we used Industrial Fine Lime (limeflour) supplied by McDonalds Lime (72% Holcim owned). This product has a top size of 125μm with an average particle size of 17μm.

Our first production trial involved making a half sized load under normal operating conditions. This load was tested at the plant for slump, air content (for interest sake only), yield and 5 cylinders for strength testing. This load was then delivered to the site with actual transit time being checked with information obtained anecdotally. On arrival at site the concrete was remixed, and a similar set of tests carried out. The results are shown in Table 2. The concrete was then remixed every 15 minutes and a sample taken for slump testing. This was continued until the resulting workability was below 120mm. This took 3½ hours from arrival at site. The results obtained convinced the construction team that there was no need to adjust the retardation at that stage, but this was to be monitored as normal throughout the project. Our road loading laws allow only 5.0m^3 to be carried in 3 axle trucks, and 6.4m^3 in 4 axle trucks, but with the flowability of this mix, and the gradient experienced in a couple of sections of the road it was resolved by us to limit loads to 4.0m^3 in 3 axle trucks and 5.0m^3 in 4 axle trucks. A typical pour sequence involved the plant batching the first load for a pour and a technician checking the slump prior to it leaving the yard. The required slump at the plant was approximately 220mm with the concrete appearing to be on the point of segregation. The truck would travel to site after being cleared by the technician. That technician would then also travel to site and reslump the load. If there had been excessive slump loss to the point of the on site slump being less than 180mm, there was agreement with the Construction Alliance for the technician to adjust the workability using admixture only. The first truck would be positioned to discharge the concrete but the process waited until the second truck was on site and the sample for testing had been obtained. Only at that point did the construction supervisor and site engineer allow concrete to be poured. The first load always involved our driver needing to discharge the concrete as quickly as the bowl would allow without spillage over the sides of the truck chutes or the funnel at the top of the tremmie pipe. During the change over of trucks the construction team would withdraw a length of tremmie pipe prior to the next load being discharged. Every load during tremmie pours would have an on site slump test taken, and every pour had strength test cylinders taken, with early age information being used to decide when topping up could take place.

THE CHALLENGES OF PRODUCTION

As noted earlier, this concrete was to be produced from a plant that is based in a rural service town. This presented a number of challenges including;

- Only one silo for cement or other Supplementary Cementitious Materials (SCMs) or Mineral Components (MICs)
- A loader fed plant
- A truck mixing plant
- A travel time of approximately 45 minutes
- A buoyant rural economy driving strong spending on farm infrastructure
- A pouring programme that was a constant work in progress as the dam foundations changed for each drilling sequence.

The single silo presents a major challenge for technical concrete as any stabilizing or filler agents have to be manually handled into the mix. In this case the limeflour was delivered in 25kg bags that were added on top of the aggregate after weighing and before discharge into the truck. Whilst there was nearly 2000m^3 poured in this project over two years, there was insufficient margin and long-term justification to add a further silo into the system. The existing ground pressure pod is used at all times to ensure there is one load of cement (approx. 25t) available as soon as possible after the pod is transferred to the main silo.

Using a loader fed plant to make this challenging concrete was considered by some to be high risk. Our experience with this particular plant and its staff gave us confidence to take on that challenge. Moisture contents of the two fine aggregates were checked prior to any concrete being made, and the appropriate mix card selected. A total of four moisture combinations were in place, and these proved adequate to cover all conditions. It is worth noting here that the climate in the Waikato is mild, with summer temperatures in the mid 20°Cs and winter generally above 0°C with some frosts but no issues around frost damage to the concrete if it is looked after during its early life.

It is generally considered difficult to be successful long term in making high workability technical concretes in truck mix plants, primarily due to the difficulty in imparting sufficient energy to the concrete. In this case we set out a stringent process around the amount of mixing required, the sequence of addition of constituents and a requirement that every load be personally inspected by the plant operator, even when the plant was busy with a number of other projects on any day. In particular we insisted that the superplasticiser was added only after a minimum of 70 revolutions of the bowl, then the concrete being brought back to the mouth of the bowl to have the admixture spread across the top of the concrete. This sequence is that recommended by the admixture suppliers. It is a testament to the staff that throughout the project there were no loads rejected for being too workable and therefore in danger of segregating. This project happened during a buoyant time in the economy with many dairy farms merging and requiring new milking sheds and feed pads, along with a strong residential housing market keeping our everyday clients busy.

The original pouring programme for this project suggested that it would take approximately 12 to 18 months to complete the task. As it turned out, the drilling was slower than expected with every series of holes providing new challenges, and the concrete was delivered over a period of approximately two years. From a production perspective this was helpful rather than a problem as all pours were carried out during what we would recognise as normal working hours.

SAMPLE TAKEN AT	TESTED AGE				
	1 Day MPa	4 Day MPa	7 Day MPa	14 Day MPa	28 Day MPa
Plant	5.3	21.6	31.8	35.7	49.2
Site		31.9	40.8	41.5	51.5

Table 2: Test results for Trial Batch of concrete

OUTCOMES

Producing highly flowable concrete is always a challenge. The dangers of segregation niggle in the back of a mix design engineer's mind constantly. Further complications are added when constituents have to be added manually, when the concrete has to be delivered some distance from the plant and communication is difficult, and when the life of the concrete has to be extended. In this case all these factors were in place and those fears were proven to be unfounded. The concrete had to be right as removing unsatisfactory loads was going to be as big a challenge as preparing the slots for good concrete. Strength results throughout the project never once caused any concern, 7 day results were consistent enough to remain confident of 28 day compliance, and this proved to be the case.

A major acceptance criterion for the contractors was complete filling of the cavities. This was checked by drilling a number of cores to ensure there was continuous concrete throughout. These cores were continuous in general, and when they were not the engineers knew in advance that there was a likelihood of this from the information they gathered as the drilling of the slots took place. From our point of view this proved that we had provided a concrete that performed as requested by the Arapuni Dam Alliance.

This project required over 400 deliveries of concrete to a remote location where cell phone coverage was almost non-existent. By being involved from the very earliest opportunity, we as concrete producers were given the best possible chance of success. The Alliance model used to carry out the project was extended in effect to us as a supplier of a critical product. Dialogue with the Alliance partners was easy and open, and good feedback was provided throughout the project. Our staff were treated as part of the project team, technicians spent long hours on site some days with early starts relatively common and winter weather that was challenging at times.

This was a project that required a specialist concrete that self consolidated. The technology is well enough understood to enable this to be made with relative ease. The challenges that the particular conditions of this project provided proved that it is possible to manufacture the concrete successfully in a low technology plant. What is required for this type of project is a strong process that is developed with input from the staff that is going to have to carry out the work. With the buy in of the staff the success is almost certainly assured if a team environment also exists between all parties.

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