THE DESIGN AND CONSTRUCTION OF THE ROTOTUNA RESERVOIR POST TENSIONED FLOOR SLAB ON GRADE

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SUMMARY

The Rototuna Reservoir project is located on Kay Road in Rototuna and has been pitched as a critical piece of city infrastructure, and, is one of a suite of projects taking shape across Hamilton. A rectangular reservoir was selected to provide the greatest storage volume within the selected site for the 24-megalitre tank. This paper will focus on the design, construction and the coordination challenges.

INTRODUCTION

Currently 90% of Hamilton City's stored water supply is on the western side of the Waikato River and the council relies on strategic pipes crossing the river if there's an emergency. The Rototuna reservoir will not only help with supply and pressure in the north of Hamilton; it also helps to meet the increasing requirement for storage, fire-fighting ability and supply options throughout the network. With an overall budget of $19 million, once completed the Rototuna Reservoir will be the City's largest reservoir.

Figure 1. Rototuna Reservoir

The tender design scheme documented by Opus detailed that the reservoir would be constructed of cast in-situ conventionally reinforced concrete and would have two cells with internal dimensions of 60.0 x 31.0m each. Consent conditions limited the maximum height to 8.0m and the operating water depth would be up to 6.5m.

Hawkins and Grouting Services proposed an innovative alternate design that included post-tensioning to the base slab of the reservoir and post-tensioning to the external and internal walls. The external and internal walls were to be post tensioned to provide strain compatibility between the base slab and walls.

The final solution significantly reduced the number of pours and the length of cold joints within the system.

The structural system was assessed in terms of current expectations for flexibility, adaptability, cost and constructability. The main walls, columns, roof slab and roof beam would generally remain as per the Opus design. The base slab was designed using loads provided by Opus to transfer vertical and horizontal loads from walls into the base slab and into the foundations of the reservoir. Resistance to lateral loading from wind and earthquake forces would be provided by the internal and external walls of the reservoir as designed by Opus.

A collaborative approach by all stakeholders was required to ensure the original design intent was maintained.

The reservoir base slab was ultimately designed to be constructed in two separate pours, coupled together with post tensioning and conventional reinforcement. A total of 1,750m3 of concrete, 38t of post tensioning and 85t of reinforcing was used in the construction of the base slab.

Figure 2. Pour 1

DESIGN SOLUTION

Original Structural Concept

The reservoir roof is designed as a one-way flat slab without any connection to the supporting beams and walls. This allows the roof to expand/shrink due to thermal movements without inducing loads in the reservoir walls. Seismic restraint of the roof is provided by the nibs and dowel bars that allow limited movement.

The walls are designed as 8m high reinforced concrete walls. Cast in situ capping beams are provided on top of the walls and pre-cast roof beams are provided in both directions to tie the columns to the top of the wall. This helps resist seismic loading by frame action and reduce the hydrostatic moments at the base of the walls.
The walls are 600mm thick at the base tapering to 300mm at the roof support beams. The roof is supported on a uniform grid of 72 number concrete columns (400mm square) and 170 number concrete beams (450mm wide by 600mm high).

The base slab was originally designed as a 450-600 mm thick conventionally reinforced concrete slab. The base slab was designed to be poured in 25 pours with construction joints dividing the base slab into 5 parts in each direction. This was a risk to Hawkins as there was 500m of potential leak points that would not be accessible once the tank was filled. Detailed settlement calculations from the geotechnical investigation predicted large deflections in the centre of the reservoir which was deemed to be excessive without the consideration of ground improvement. Piling and pre-loading options were considered and it was decided to preload the site with approximately 30,000m3 of rock due to its easy availability.

Alternative Post Tensioned Proposal

The alternative design proposed was a 250mm thick post tensioned base slab which was tapered to a 700mm thickening at the base of the walls to deal with the wall moments and base shear. The preliminary design proposal was to build the entire slab in a single pour, but due to the footprint of the tank and restricted working room around the perimeter, a construction joint was added and the slab was built in two pours. Post tensioning strands were also incorporated into the walls to ensure that there is strain compatibility between the walls and the base slab.

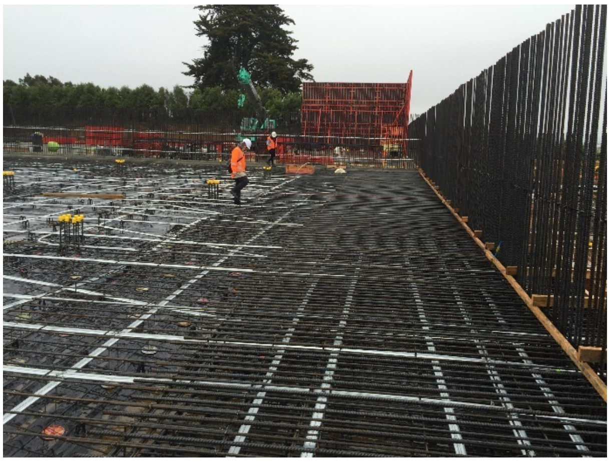

Figure 3. Perimeter thickening and reinforcement

Design Standard

The design of the post tensioned base slab was based on NZS: 3101:2006-Concrete structures Part 1, NZS:3106:2009-Design of Concrete Structures for the Storage of Liquids and AS/NZS 1170.0-Structural Design Actions Parts 1 to 5. The concrete structure was designed to have a minimum "design life" of 100 years as per Clause 3.1 of NZS:3101.

Liquid Tightness

The base slab was designed to comply water tightness class 1 in accordance with NZS 3106, which is categorised by limiting leakage to a small amount which results in some surface staining or damp patches to be acceptable. To meet this tightness standard, the limiting crack width was calculated to be 0.17mm.

Limiting Stresses in Pre-Stressed Concrete

The final stresses within the post tensioned slab were based on the limits contained in NZS 3106. The compressive stress applied by the post tensioning in the base slab is approximately 1.6MPa. Compressive stresses at the construction joint range between 0.8MPa and 0.95MPa.

Long term tensile stresses were generally limited to 1.58MPa within the base slab. Localised areas where the stresses exceeded this value were supplemented with steel reinforcement. These requirements were checked under both an ultimate load case and working stress limit, and, considered the combination of dead loads and hydrostatic loads.

Short term tensile stresses were limited to 3.16MPa within the base slab. Areas which exceeded 3.16MPa were supplied with steel reinforcement. These requirements were checked under an ultimate load case comprising of dead loads, hydrostatic loads and seismic loads.

Figure 4. Coupled construction joint

Foundation System

The base slab was analysed using finite element analysis software RAM Concept and the subgrade conditions were modelled as an area spring. Subgrade modulus of 18000 KN/m3 was obtained from the geotechnical engineer and was used as the vertical spring constant for modelling the base support.

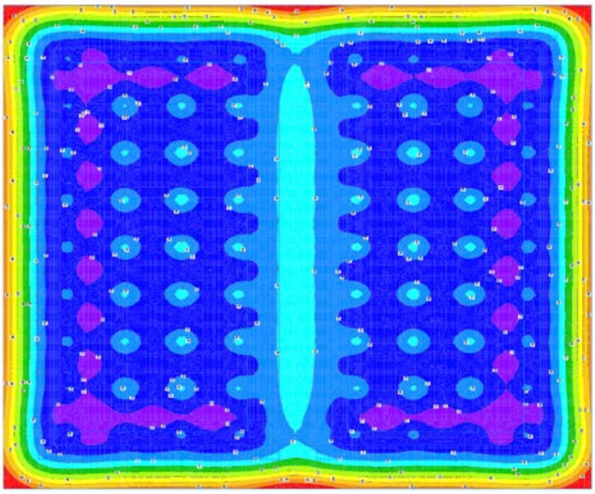

Figure 5: Deflection plot from RAM

A sensitivity analysis was carried out to understand the effects of localised weaker soils by carrying out a series of analysis with spring stiffness varying from 5 up to 35kPa/mm.

Design Loads

The base slab was designed to transfer the vertical and horizontal loads produced by the dead loads, hydrostatic loads and seismic loads. The dead loads included the self-weight of the walls, columns, roof and a uniformly distributed load of 0.25 KPa applied on the roof.

The water depth was limited to 6.5m for calculating both hydrostatic and seismic loads. A uniformly distributed load of 65 KPa was used for the water loads. The base shear and over turning moments from the wall were analysed for different configurations of water depths in the two cells and were transferred onto the slab.

Wave action due to seismic action was considered by Opus in assessing the lateral effects.

Movement and Shrinkage

Pre-stressing the base slab creates a potential difference in creep and shrinkage rates between the base slab and the walls. To deal with this, post tensioning strands were added to the bottom third of the wall and the walls were pre-stressed at a similar level of compression to the slabs to ensure there is strain compatibility between the walls and the base slab. This was done to ensure that all elements contain similar shrinkage characteristics. The effects of drying shrinkage strain within the slab would be reduced as the slab is stressed in two stages. The initial stress reduces the risks associated with any early shrinkage strains and the final stress ensures the base slab has an average effective pre-stress of approximately 1.6MPa.

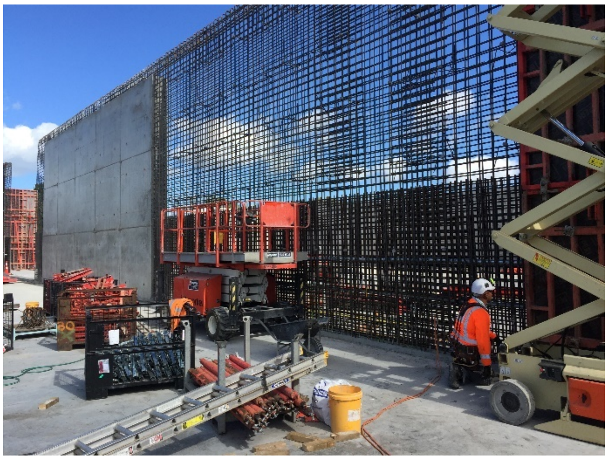

Figure 6: Wall prepared with post tensioning ducts

CONSTRUCTION

Hawkins was selected as the main contractor.

The principal subcontractors engaged on the job for the reinforced concrete construction were Grouting Services (post-tensioning) and EDGE (post-tensioning design), Connell Construction Ltd (formworkers) Steel and Tube (reinforcement supply and fix), Schick Civil Construction (earthworks), Wrathalls (concrete placing), wall shutters and external vibrators supply (Peri).

Allied Concrete was used to supply the 4500m3 of concrete while Pioneer Pumps were engaged to carry out the concrete slab pumping utilising 52m and 42m booms and Valid Concrete Pumping for all other pours.

Subbase Preparation

The 8m high pre-load rock pile was removed in March 2016 and Hawkins got underway with the preparation of the subbase. It was essential to ensure that the upper portion of the subbase was of uniform material and density to provide uniform support. The subbase drainage was installed and prepared to reflect the falls in the slab to maintain the uniform slab thickness in the 250mm thick area. This involved the placement and grading of imported fines.

The slopes at the edge thickening were also graded smooth to reduce restraint. A slip membrane consisting of two layers of polythene was laid on top of the subbase to reduce the sliding friction between the slab and the subbase.

Figure 7: Subbase preparation

Formwork and Set Out

A coordinated set of post tensioned shop drawings were produced which enabled the rapid erection of the perimeter shuttering and installation of the post tensioning anchorages. This also assisted in pre-determining the set out for the vertical reinforcement steel around the post tensioning anchorages thereby removing conflicts between post tensioning and reinforcing elements.

Post Tensioning and Conventional Reinforcement

The order in which the post tensioning strand and reinforcement is installed is critical due to the profiled alignments of the post tensioned tendons and the phrase “PT takes priority” was adopted by the site team to ensure good continuity of work between the respective trades.

Once the perimeter shuttering had been erected with pre-formed slots for the strand, the post tensioning anchorages were bolted in position. The reinforcing steel installation commenced at the same time and the pre-planning meant that clashes were minimised and cover requirements were easily maintained.

The slab edges were thickened at the base of the slab to deal with the base shear and moments from the wall and this area was heavily pre-stressed in conjunction with a heavy amount of reinforcement from both the slab and wall. Typically, the slab edges had 5-strand tendons at 750mm with HD16 and HD25 L-bars placed top and bottom at 200mm spacing. The vertical wall reinforcement at the slab junction comprised HD25 bars at 100mm centres on both faces with 1200mm cogs lapping with the bottom slab reinforcement.

Sequencing and placement was critical and a combined crew of 32 men (6 from the post tensioning crew and 18 from the reinforcing crew and 8 shuttering carpenters) worked diligently through significant periods of inclement weather to set up the slabs ready for pouring. While the first slab was being prepared for concrete the second slab was being excavated at the same time to reduce the critical path.

Once the perimeter and bottom reinforcement had been placed, the post tensioning duct was installed and taped to enable the strands to be installed. This was followed by the placement of the top reinforcement, and, at the same time the grout tubes were installed and the ducts sealed. Tendon profiling was also completed.

The first and larger slab was prepared and poured in less than 5weeks and the second slab was prepared and poured in less than 3weeks.

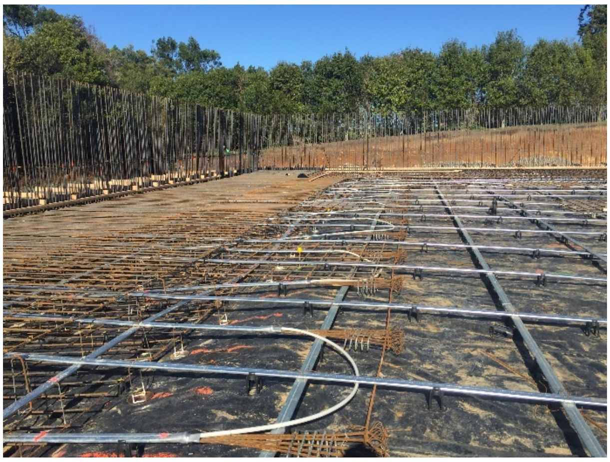

Figure 8: Post tensioning and conventional reinforcement

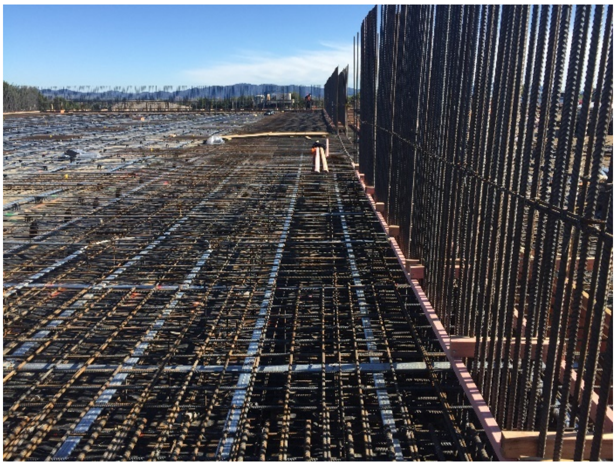

Figure 9: Reinforcement congestion

Concrete

The base slab was constructed in two pours with a construction joint adjacent to the central reservoir wall.

Concrete volumes were nominally 900m3 for pour 1 and 850m3 for pour 2. The concrete mix was a pumpable 40MPa 19mm aggregate mix with a target drying shrinkage of 750microstrain.

The scale of the project and large volume of each pour presented a challenge for the entire project team.

The concrete was despatched from Allied Concrete’s Horotiu and Morrinsville plants. Allied Concrete’s Cambridge plant was also on standby if there were any mechanical failures.

Concrete started at 3am for each pour and a working crew of 40 men was employed in the concrete placing/finishing and post tensioning/supervision operations.

Consistent delivery of concrete to the face is critical and thanks to a great team effort and people working collaboratively together, a respectable delivery and placement rate of 75m3 per hour was achieved.

Figure 10: Concrete pumping and placement

Once each pour was concreted, an initial stress was applied to the post tensioning strand when the concrete strength reached 9MPa.

Each floor was fully stressed once the concrete strength reached 25MPa with the exception of the six outer perimeter tendons on each edge of the slabs, perpendicular to the construction joint. These were finally stressed in conjunction with the wall post tensioning for strain compatibility.

After final tensioning and verification of tendon extensions, all tendons were grouted using a special post tensioning grout mix that provides 0% bleed and a compressive strength of 70MPa at 7days.

Wall, Column and Roof Construction

With over 300 lineal meters of reservoir wall (including the 60m central dividing wall), 72 supporting roof columns and close to 1500 lineal metres of roof beam, construction methods that would ensure quality and timely delivery was of great importance.

Figure 11: Wall reinforcement and Peri formwork

The perimeter walls are 8m high and 600mm thick at the base tapering to 300mm thick at the underside of the roof. The central dividing wall is 500mm thick over its entire 8m height. This equates to approximately 3.3m3 of concrete per lineal length of wall or a total in excess of 1000m3. A proprietary Peri wall formwork system complete with external vibrators imported from Italy was selected to form the walls and a significant amount of planning went into the sequencing, including concrete mix trials. A 40MPa 13mm aggregate pump mix was used for the walls and concrete delivered via a tremie pipe installed to the base. The wall post tensioning had to be detailed around the tremie pipe location given the tapering wall geometry. The Peri wall formwork system was quick to install and the wall was successively completed full height in 102m to 20m long panel sections on a hit and miss basis.

Figure 12. Completed wall off the form

The supporting column and roof construction sequencing meant that sections of the wall had to be left out to enable the construction lifting equipment to operate on the post tensioned base slab.

Figure 13. Wall section left out

The supporting columns were converted from in-situ concrete to pre-cast concrete to expedite the construction programme. The columns were connected to the base slab with grout sleeves which enabled the use of short reinforcing starter lengths projecting from the base slab. This allowed the rough terrain cranes and elevated work platforms to move around freely without having the traditional 1m starter bars getting in the way and being damaged. The columns were placed and propped to immediately enable the lattice of pre-cast roof beams to be placed progressively. This was followed by the installation of 280 ribspan precast rib elements and in-situ concrete roof topping.

Figure 14. Precast columns, in-situ roof beams and unispan ribs

The wall post tensioning included 3No-6x12.7mm multi-strand tendons in the perimeter walls and 2No-6x12.7mm multi-strand tendons in the central wall. Due to the construction sequencing, the walls could not be tensioned until the roof structure had been completed.

The Rototuna Reservoir took 15 months to complete and involved more than 53,000 manhours.

The Rototuna Reservoir recently passed the static water test on its first pass with flying colours and Hawkins is currently working through the final processes of the commissioning phase and completion of external landscaping.

Lessons Learned

The success of the post-tensioned concrete slab was very much the result of a team effort from all those involved.

As with all projects there are things that do not go according to plan. Fortunately, these were limited and are outlined below;

The consistency of the concrete during the start of the first pour was extremely varied and proved difficult to pump and place. Unexpected quick drying further complicated the pour and after some 30m3 had been placed, it was decided to abandon the pour. The affected area of slab was subsequently broken out, damaged reinforcement / post tensioning components replaced and the pour successfully completed a week later.

After the construction of the second pour, and 2 weeks after the completion of the final stress, fine cracks were noticed in pour 2 originating from the construction joint and generally running perpendicular to the joint. The cracks were spaced 6m to 8m apart with lengths varying from 3m to 12m and widths measured to be generally under 0.1mm – 0.15mm.

The root cause of the cracking was put down to the differential drying shrinkage between successive concrete pours (effectively pour 2 was shrinking at a faster rate than pour 1 and as the slabs were coupled together, pour 1 provided some level of restraint to pour 2).

It is well understood that the application of a post tensioning force puts the concrete in compression and controls the propagation of cracking in an unrestrained environment.

The cracks were monitored for several months and they closed up to a maximum width of less than 0.1mm. This is due to the compressive force applied with the post tensioning. The residual cracks were then grouted with a polyurethane resin.

SUMMARY

Post tensioned concrete is a well-established method of construction for water retaining structures.

The conversion of the base slab from conventionally reinforced concrete to post tensioned concrete resulted in savings to the Principal in the order of $300,000.

The construction system developed for this reservoir proved to be very successful and enabled the quality objectives and programme timeline to be achieved.

Early age shrinkage strains and the monitoring and control of such is crucial when detailing large scale concrete pours. The isolated nature of cracking in post tensioned slabs can be advantageous should any repair or remedial work be required.

REFERENCES

[1] www.hawkins.co.nz
[2] www.edgece.com
[3] www.groutingservices.co.nz

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Electrical – One Electrical
Acrow – Shoring and scaffolding
Preco – Precast supply
Pollocks – Cranes
Wrathalls/The Concrete People – Concrete placing
Concrete Pumping – Valid and Pioneer