RETROFITTING RESILIENCE – RICHMOND RESERVOIRS

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ABSTRACT

Lessons learnt from the 2011 Christchurch earthquakes led the Tasman District Council to upgrade its three key concrete water storage reservoirs in Richmond. The work stemmed from a desire to minimise the risk to Council assets located in a fault zone. Initially, the project started with the installation of flow control valves linked to flow meters.

Flow control valves prevent reservoirs from emptying in the event of a major pipe failure. The key success criteria for the Council were ensuring a continuous water supply to its customers and minimising shutdowns during the construction works.

During a review of the existing as-built drawings however, it was discovered that the wall to floor connections of these concrete reservoirs were likely to fail during a seismic event. The review highlighted a connection deficiency which was common in concrete tanks that were constructed before the mid 1970's. For some circular precast reservoirs the base of the precast wall panels simply rested in a slot with no reinforcement connecting the components together. Due to this deficiency, the scope of the original project was extended and a structural analysis of the three reservoirs undertaken.

This paper highlights the key issues and describes the lessons learnt from both the installation of the flow control valves and the completion of structural strengthening works at each of the reservoirs.

KEYWORDS

Reservoir, Seismic, Resilience, Water supply, Shut down, Risk

1 INTRODUCTION

1.1 BACKGROUND

The safety and performance of the Tasman District Council's key infrastructure assets are regularly monitored to assess whether they are at risk from seismic events. This stems from a desire to minimise the risk, particularly as many Council assets are located close to a fault zone.

Following the 2011 Christchurch earthquakes, the Tasman District Council assessed its three key concrete water supply reservoirs in Richmond. The review compared how similar reservoirs had performed in the Christchurch earthquakes of 2010 and 2011. Initially, the project scope was to install flow control valves linked to flow meters. However, during the planning for this work, and in the light of the performance of concrete reservoirs during the Christchurch earthquakes, it was discovered that the wall to floor connections were likely to fail during a seismic event.

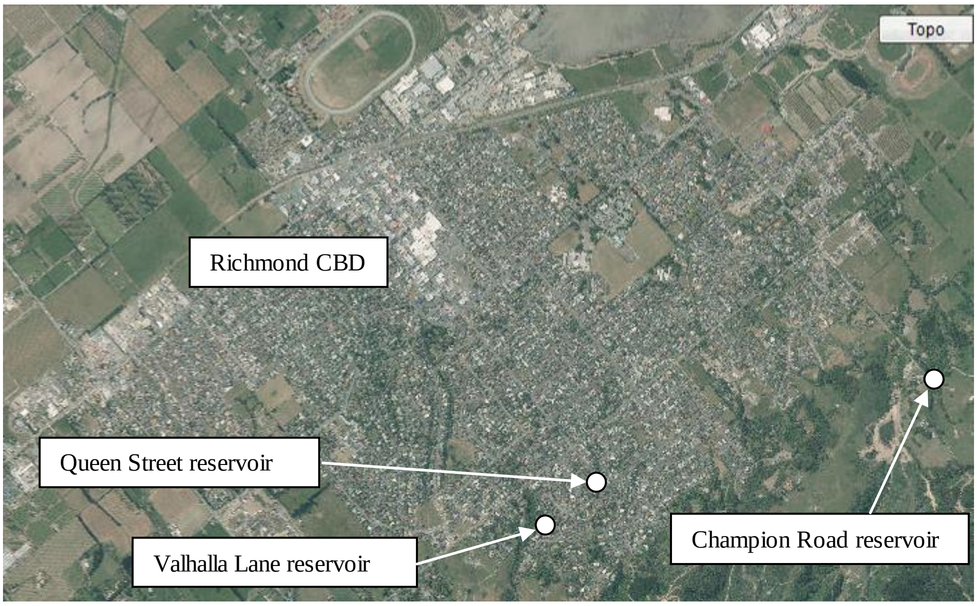
1.2 LOCATION OF THE WORKS

The town of Richmond is the largest urban settlement in the Tasman District with a population of over 15,000 and located approximately 15km south-west of Nelson.

Figure 1: Richmond is the largest urban settlement in Tasman District

The three concrete water supply reservoirs in Richmond are located at Valhalla Lane, Queen Street and Champion Road as shown in Figure 2.

Figure 2: Location of the three concrete water supply reservoirs in Richmond



1.3 PROJECT SCOPE

As described, the original project scope was for the installation of flow control valves and flow meters to prevent the reservoirs from emptying in the event of a major pipe failure. The concern about wall to floor failure however, was identified when the existing as-builts were reviewed and so the project scope was subsequently extended to include for the structural strengthening works.

This paper covers firstly the installation of the flow control valves and then the structural strengthening works.

2 FLOW CONTROL VALVES

2.1 COUNCIL SUCCESS FACTORS

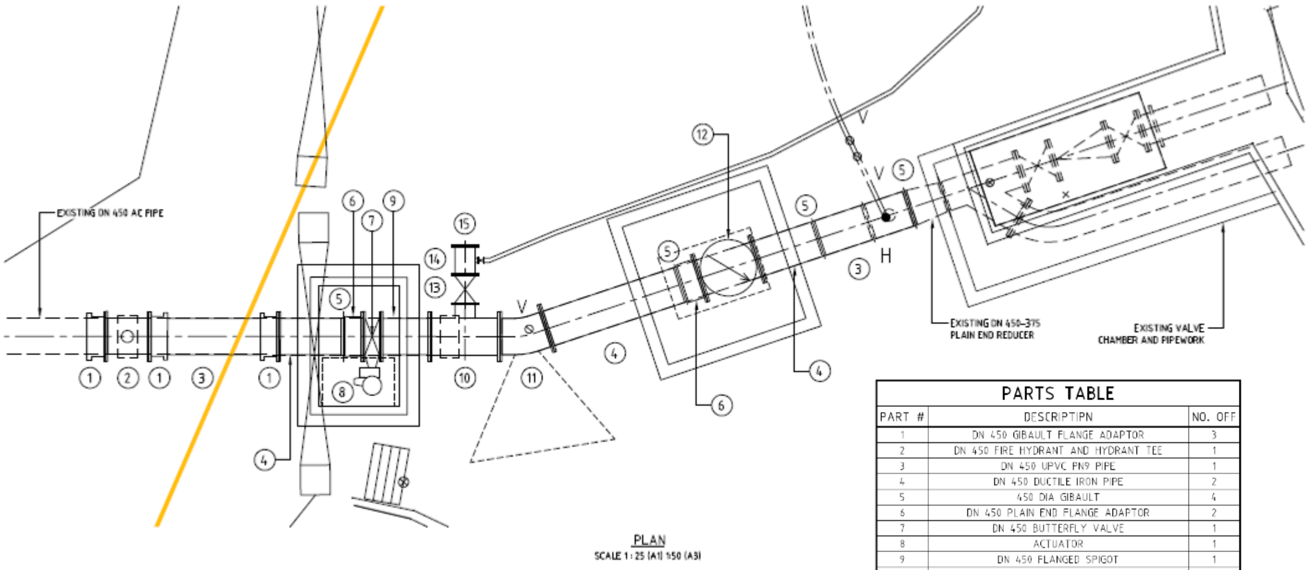
The key success criteria for Tasman District Council during the installation of the flow control valves and meters was to ensure a continuous water supply to its customers and to minimise the reservoir shutdowns during the construction works.

Whilst the design component was fairly conventional and the duration of the construction works at each site relatively short, it was the planning of the water supply shutdown and pipework installation that was critical to the success of the initial project.

2.2 DESIGN

The drawing below shows the typical design layout of the flow control valve and flow meter installed at each reservoir. Whilst the order of the fittings was generally the same at each of the three reservoirs each had site specific constraints such as the diameter of the pipework, the chamber sizes and the available footprint at each site.

Figure 3: Layout of the flow control valve, flow meter and pipe fittings at Champion Road reservoir



PARTS TABLE		
PART #	DESCRIPTIPN	NO. OFF
1	DN 450 GIBAULT FLANGE ADAPTOR	3
2	DN 450 FIRE HYDRANT AND HYDRANT TEE	1
3	DN 450 UPVC PN9 PIPE	1
4	DN 450 DUCTILE IRON PIPE	2
5	450 DIA GIBAULT	4
6	DN 450 PLAIN END FLANGE ADAPTOR	2
7	DN 450 BUTTERFLY VALVE	1
8	ACTUATOR	1
9	DN 450 FLANGED SPIGOT	1
10	DN 450x250 FLANGED TEE	1
11	22.5° DN 450 D.I FLANGED BEND	1
12	DN 450 MAGFLOW	1
13	DN 250 FLANGED SLUICE VALVE	1
14	DN 250x50 FLANGED TEE	1
15	DN 250 BLANK FLANGE	1

2.3 RESERVOIR SHUTDOWN PLANNING

A number of planning workshops were held with MWH, Council staff and its maintenance contractor, Downer, to discuss the options for each reservoir shutdown. These included discussions with local industrial users, options for re-directing pumped flows and scheduling the works during low flow periods to minimise water supply outages. Further mitigation measures that were discussed included undertaking reservoir shut-down ‘practice runs’ and checks to ensure that all the required materials and plant (including spares) were on site ahead of time.

2.3.1 METHODOLOGY

The primary output of the initial planning meetings was to develop a reservoir shutdown and pipework installation methodology for the Champion Road reservoir, the first of the three to have the works undertaken.

This methodology included ensuring that the pump stations within the network were at full capacity to allow supply to continue to domestic and industrial users during the shutdown period. For this to occur, a specific sequence of closing and opening valves throughout the local network was required.

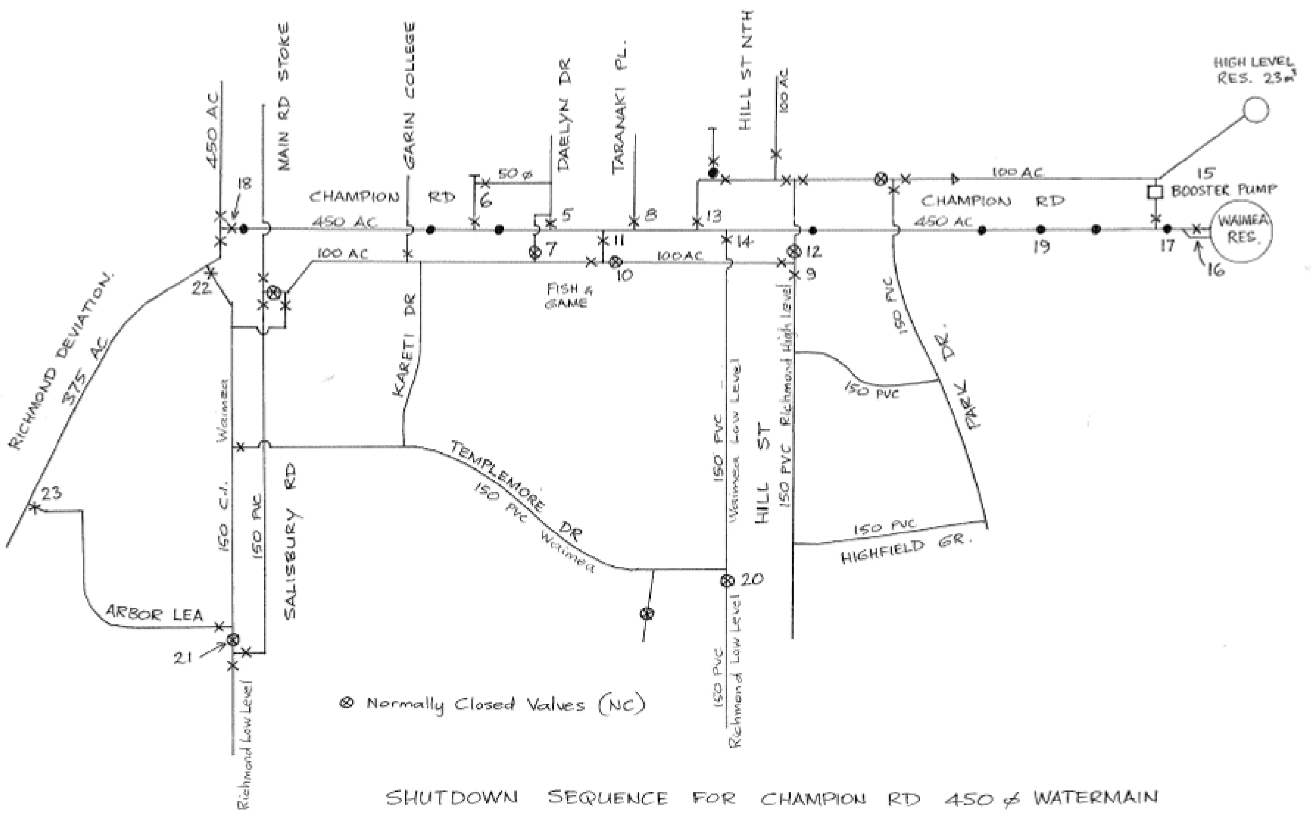
The schematic in Figure 4 shows the valve locations within the local network and the order in which they were required to be either closed or opened.

The methodology also documented the various notifications that were required; this comprised of water supply shutdown notices, water conservation notices and notification of water pressure fluctuations for the three main affected industries.

In addition, the Contractor was required to demonstrate how the reservoir shutdown procedure would be managed and the physical works constructed, as well as documenting how the water supply would be maintained, including for any back-up supply e.g. water tankers. It was also important that consideration was given to preparation of contingency plans e.g. in the event of bad weather, power outages, unforeseen delays etc.

Confirmation was also required that the materials and fittings ordered were as required to fully complete the connection and that spare components and extra fittings were readily available if required on the day of the shutdown.

Figure 4: Schematic of the valve shutdown sequence for Champion Road reservoir



2.3.2 PRE RESERVOIR SHUTDOWN CHECKS/TESTS

Ahead of the each of the actual shutdown and pipework installations it was decided to undertake some pre-shutdown checks. This included some as simple as confirming the location of all the valves and ensuring they were operational. This low cost and simple check proved invaluable as some were difficult to find having been obscured by vegetation, which would have resulted in delays on the day.

Other pre-shutdown checks/tests included installation of pressure loggers at key locations in the local network to ensure that adequate pressure was able to be maintained during the shutdown when the supply would be kept fed from the water supply pump stations instead of the reservoir.

2.4 SHUT DOWN AND CONSTRUCTION

Whilst the planning stage was the most rigorous aspect of the project life cycle, the success of the actual shut down and construction on the day determined the final outcome.

Sequencing the design, shutdown planning and construction to be completed at one site before starting the next, whilst lengthening the overall programme, allowed for lessons learnt from each of the previous reservoirs to be incorporated into the next.

For example, at the Champion Road reservoir, the first to have works undertaken, on-site delays were encountered where a number of line and level adjustments had to be made iteratively to account for the change in direction in the pipework (as shown in photograph 1). This meant the overall duration of the construction works was a number of hours longer than anticipated. To mitigate this, subsequent designs included for more flexible fittings to allow for easier adjustments to the line and level of any pipework connections.

Photographs 1 and 2: Installation at Champion Road (left) and Queen Street (right) reservoirs

2.5 OUTCOMES

Despite some of the unforeseen issues during construction, the installation of the flow controls at each of the reservoirs went smoothly and achieved the Council's success factors of maintaining supply to customers and minimising reservoir shutdown periods.

All parties agreed that the time invested during the planning phase as well as incorporating lessons learnt for subsequent reservoirs was crucial to this success.

3 RESERVOIR STRENGTHENING

3.1 AS-BUILT DRAWING REVIEW

As part of the flow control valve and meter installation, the existing as-built drawings were reviewed. The review highlighted a connection deficiency in the wall to floor connection and wall to roof connection in these concrete reservoirs. This was common in concrete tanks that were constructed before the mid 1970's where in some circular precast reservoirs the base of the precast wall panels simply rested in a slot with no reinforcement connecting the components together (see Figure 5).

These connection details were developed for static loading only (which is satisfactory under normal conditions since forces are radial). During a seismic event however, some of these tanks are susceptible to lateral forces resulting in the wall moving and causing failure. More recent designs have the walls physically fixed into the slab or the ring beam to prevent failure.

Figure 5: Wall in a slot - no floor connection (left) wall connected in slot – no floor connection (right)

3.2 LESSONS LEARNT FROM THE CHRISTCHURCH EARTHQUAKES

Studies of the performance of concrete potable water reservoirs in the February 2011 Christchurch earthquakes found that the wall to floor and wall to roof connections were typically vulnerable. Damaged connections were observed in many reservoirs, for example:

- deformed/fractured dowel bars,
- concrete spalling at the top of the wall panels at the dowel location,
- sections of overhanging nib shearing off of the roof,
- cracking of the foundation ring beam,
- spalling of concrete at pilaster locations and
- noticeable movement between the wall and the ring beam.

In view of the as-built review findings and the Christchurch lessons learnt, a recommendation was put forward to Council that a structural analysis should be carried out on the wall to floor detail for all three tanks. This analysis would confirm if this detail should be strengthened. The detail between the roof and the walls of the tanks was also recommended for assessment.

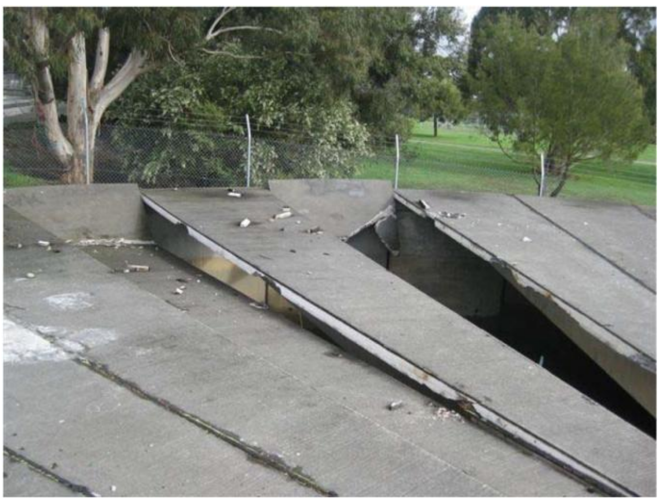
Council accepted the recommendations and the scope of the original project was extended. A structural analysis of the three reservoirs was then completed to determine the strengthening requirements.

3.3 STRUCTURAL ANALYSIS

All three tanks were constructed in the 1970s and so had been in service for 40 years. The analyses were based on a 50 year design life of the tanks.

During a seismic event, the horizontal earthquake acceleration causes the water in the tank to slosh and creates waves in the tank. If the freeboard of the tank is less than the convective wave height, a hydrodynamic pressure will be generated leading to uplift forces on the roof. This is illustrated in the photograph below of a Christchurch reservoir following the September 2010 earthquake.

Photograph 3: Damaged Denton Park reservoir roof in September 2010 Christchurch earthquake



Horizontal earthquake loading forces the walls to move relative to the floor and foundation. In order to transfer this load into the foundation, it is common practice to provide dowels across the interface between the wall and foundation beam, in which case the bulk of the load (nominally 80%), is transferred through dowel action along the side walls into the foundation (commonly referred to as membrane action). If these dowels are not provided, then the side walls can only transfer load through friction (from the weight of the wall and any supported roof) which is generally found to be insufficient for transferring the forces. The secondary mechanism that is used to resist the horizontal loading is bearing of the wall panels on the foundation perpendicular to the direction of loading; this mechanism is less desirable as it can induce high local stresses in the wall panels and foundation beam.

The horizontal earthquake load will also produce an overturning moment on the tank. As a result, an uplift force will be imposed on one side of the tank wall. The self-weight of the wall and the contribution area of the roof are generally insufficient to resist the uplift. This can result in wall failure, with the wall lifting from the socket in the foundation and loss of the pinned wall base support. In more recent design, reinforcement is provided in the wall to the foundation connection to restrain the wall from uplifting.

To comply with current codes, the reservoir roofs needed to be retrofitted with suitable connections to prevent roof uplift. Connections such as steel brackets could be bolted onto the roof slab and the wall panels.

Strengthening of the roof beams support connections also needed to be considered. This could be done with steel corbels at the beam ends to transfer the load to the wall panels or other specially developed details.

Strengthening was required to the wall and base ring beam footing connection so that the earthquake shear load would be transferred through membrane shear of the wall to the floor to prevent circumferential sliding of the wall.

3.4 STRENGTHENING OPTIONS

The assessment recommended that a number of strengthening options could be considered:

- strengthening the wall to floor only, wall to roof only or both (to current design standards)
- strengthening the wall to floor only, wall to roof only or both (to higher design standards to account for ‘sloshing’)
- a combination of the above
- additionally, the types of strengthening may be prioritised e.g. wall to floor only at all reservoirs
- or reservoir sites may be prioritised e.g. all strengthening repairs at Champion Road only.

3.5 COUNCIL SUCCESS FACTORS

As well as improving the seismic resilience of all three of these key assets another important driver was for the Council to remain within the allocated budget.

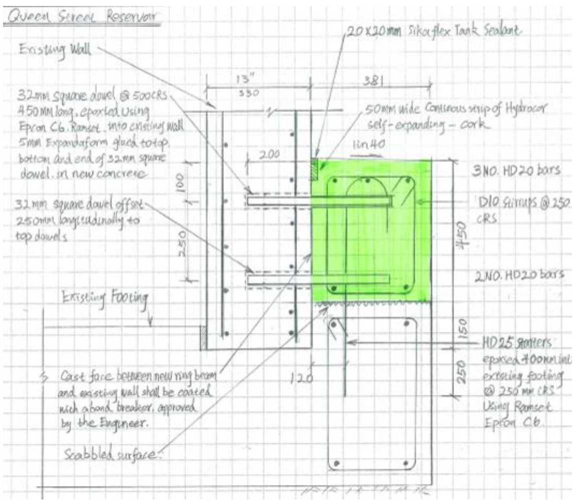
Following a review of some high level cost estimates for the various options it became clear that addressing all the strengthening works could not be completed within the allocated budget.

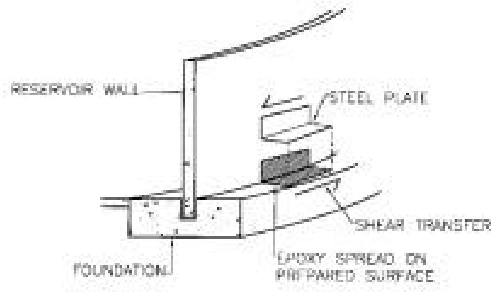
It was subsequently agreed that strengthening the wall to floor connection ahead of the wall to roof connection was the priority as tank failure at ground level had a greater consequences than that at roof level. By prioritising this deficiency, Council were able to undertake strengthening work at all three reservoirs within the allocated budget and still significantly improve the seismic resilience of each reservoir.

3.6 DESIGN

Two options were considered for the strengthening of the wall to floor connection. Firstly, retrofitting an external reinforced concrete ring beam at the base of the wall with bars connected into the wall panels and tied into the floor slab to transfer the load from the wall to the base slab through wall membrane shear mechanism. Secondly, a more specialised method of epoxy bonding angle shaped steel brackets fitted to the wall to floor connection externally.

Figures 6 and 7: Reinforced concrete ring beam detail (left) and epoxy bonded angled steel brackets (right)





As the epoxy bonded angled steel brackets was a more specialised option the reinforced concrete ring beam methodology was selected as this would be a construction technique that local contractors would have the capability for and so bring more price competitiveness for Council. This decision was vindicated with four tenders being received for the work, and the successful price under the Engineer's Estimate.

3.7 SHUTDOWN PLANNING

As the strengthening work was to the external wall of the reservoirs the works could be undertaken without any shutdown needed for two of the three reservoirs. However, for the third, Valhalla Lane reservoir, the concrete footing of the structure was 1.5m below ground. It was impractical to excavate around the reservoir to expose the concrete footing and so the strengthening work had to be undertaken internally. This required the reservoir to be drained empty for a period of time. The shutdown methodology employed during the flow control valve installation was able to be used, with some modifications due to the longer shut down period.

3.8 PROGRAMMING/SEQUENCING

As with the flow control valve installation, the works were sequenced so as to complete one site before starting the next. Again this allowed for lessons learnt from each of the previous reservoirs to be incorporated into the next. Additionally, with Valhalla Lane reservoir requiring internal works this was scheduled to be completed last, meaning the construction team would have gained a good understanding of any issues through completion of the first two reservoirs.

3.9 CONSTRUCTION

The construction involved drilling hundreds of holes in the tank base to fit steel dowels, which were then fixed into the concrete ring beam. Whilst the drilling work was of a monotonous nature, allowing an adequate programme meant the construction team were able to maintain the quality and precision of the drilling. In addition, Health and Safety requirements of working with vibrating tools restricted operator time.

Photographs 4 and 5: Inserted dowels at Champion Road (left) and beam construction at Queen Street (right)

3.10 CONFINED SPACES

The repetitive nature of the work was further complicated at Valhalla Lane reservoir. As previously mentioned, the concrete footing of this reservoir was 1.5m below ground and so the strengthening work was undertaken internally.

This created a confined spaces work environment for the construction team, and generated issues such as noise and dust. In this instance, the construction team were keen to complete the works in as short a time period as possible, which was also beneficial from a reservoir shut down perspective, and so Council approved extended work hours, including the weekend.

A further consideration that the internal strengthening work created was the disinfection process once the reservoir was to be re-commissioned.

Photographs 6 and 7: Internal strengthening works at Valhalla Lane reservoir

3.11 OUTCOMES

By prioritising the strengthening work to the wall to floor connection only, Council were able to significantly improve the seismic resilience of all three reservoirs whilst remaining within the allocated budget.

Another key factor to the successful outcome of this project as highlighted during the close out, was Council providing the Contractor with a flexible programme both in terms of duration and working hours.

4 CONCLUSIONS AND LESSONS LEARNT

4.1 CONCLUSIONS

Tasman District Council's decision to upgrade its three key concrete water storage reservoirs in Richmond stemmed from a desire to minimise the risk to Council assets located in a fault zone. The review compared how similar reservoirs had performed during the Christchurch earthquakes in 2010 and 2011 and concluded that retro-fitting options were available to provide increased resilience to these assets.

The installation of flow control valves now prevents the reservoirs from emptying in the event of a major pipe failure, and the flow meters monitor inflows and outflows and close the control valves should a seismic event rupture a trunk main.

The concrete strengthening works have provided resiliency to the wall to floor connection deficiency where the base of the precast wall panels simply rested in a slot with no reinforcement connecting the components together. This was a common deficiency in concrete tanks that were constructed before the mid 1970's.

Council's key success factors for this project were to ensure a continuous water supply to its customers and minimising shutdowns during the installation of the flow control valves and meters, and improving the seismic resilience of all three of these key assets through the strengthening works whilst remaining within the allocated budget.

This was achieved through the careful planning of the shutdowns during the flow control valve and meter installation and prioritising the strengthening solutions across all three reservoirs.

Construction of the strengthening works was completed in September 2014.

4.2 LESSONS LEARNT

There were a number of contributing factors to the successful completion of this project and they included:

- Investing in the shutdown planning time and undertaking pre-reservoir shut down checks. This minimised any unforeseen circumstances or surprises on the day of the physical works.

- Completing the works at one reservoir before starting the next, whilst lengthening the programme, allowed lessons learnt to be incorporated into the next. Sequencing the easier sites first also helped the construction team fine-tune their construction methodology.

- Providing flexibility in programme duration and also the working hours, particularly where works were labour intensive and monotonous. This helped to ensure a high standard was maintained throughout construction.

- Prioritising the higher risk deficiencies. This enabled the improvement of the seismic resilience of all the three reservoirs instead of addressing all the deficiencies just at one site. This also allowed the works to remain within the allocated budget.

- Selection of a more traditional construction method allowed more local contractors to tender for the work and drive more cost competitiveness. The alternative construction method was specialised, unlikely to attract local contractors, more likely to incur higher establishment costs and also have less flexibility in programme due to the prospective tenderers other commitments nationally.

ACKNOWLEDGEMENTS

Downer NZ for the installation of the flow control valves and meters and Kidson Contracting Ltd. for the construction of the concrete ring beams.

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