

Lessons learned from one of New Zealand's most challenging civil engineering projects: rebuilding the earthquake damaged pipes, roads, bridges and retaining walls in the city of Christchurch 2011 - 2016.

## Huntsbury Reservoir - Post Earthquake Reconstruction Ozwater 2013 conference paper

**Story:** Huntsbury Reservoir

**Theme:** Design

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A paper prepared for the Ozwater 2013 conference detailing the story of the damage to, and subsequent repair of, Huntsbury Reservoir.

This document has been provided as an example of a tool that might be useful for other organisations undertaking complex disaster recovery or infrastructure rebuild programmes.

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# HUNTSBURY RESERVOIR POST EARTHQUAKE RECONSTRUCTION

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## Abstract

The 22 February 2011 Christchurch earthquake damaged the 35,000 cubic metre Huntsbury reservoir and all stored water escaped. The 59 year old reservoir was the principal potable water storage facility in the city. A geological shear zone on a diagonal orientation across the site was subsequently discovered.

Partial replacement water storage was deemed essential by December 2011, and alternative sites were available.

Challenges this presented included:

- Could the 59 year old structure be reconstructed to reliably store water?
- Was a safe construction methodology feasible?
- Could investigation, design, construction and commissioning be done in the timeframe?
- How extensive was the shear zone, what future earthquake movements could be expected and what constraints did this impose?

This is a story of how teamwork, integration of design, construction and operations, prompt decision making, astute risk assessment and consultation with the community reinstated water storage on Huntsbury Hill.

The implications of the performance of the Huntsbury reservoir for tomorrow's infrastructure relate primarily to strength and watertightness of the structure and connected pipework, ability to reliably isolate the stored water in the event of an emergency, the durability of concrete and detailing to minimise maintenance.

The authors represent the design, construction and operator organisations involved in the project.

## Key Words

Reservoirs, Christchurch, Earthquakes, Resilience, Design, Construction, Operation.

## Introduction

When events such as a major earthquake occur, restoring vital infrastructure such as power, water and wastewater services to the community is critical. There had been an earlier earthquake in Christchurch in September 2010. This caused damage to older buildings in the city, and some land and infrastructure damage. Management of infrastructure repairs following the September 2010 earthquake was the responsibility of the Infrastructure Recovery Management Office (IRMO), and design and construct teams (including Fulton Hogan/Beca) were appointed for repair work in four separate zones in Christchurch.

The Huntsbury No 1 reservoir was in the Fulton Hogan/Beca zone and following the damage sustained during the 22 February 2011 earthquake, resulting in the loss of all stored water, responsibility for assessment and repair was assigned to Fulton Hogan/Beca.

In consultation with the Christchurch City Council it was determined that the water supply system operation could continue without Huntsbury No 1 storage and the associated pump station until the December 2011-March 2012 summer period. This was a difficult time for the Council operators as not only was the main storage facility out of operation, but there was extensive damage to

pipework, reservoirs and pump stations elsewhere in the water supply network.

The reservoir was a reinforced concrete structure with plan dimensions of 77.4m by 63.0m, a clear internal height of 7.9m and a water depth of 7.25m. The roof was overlaid with soil and grassed, and walls ranged from fully buried to exposed as the site is cut into the side of a sloping section of land. Refer to Figure 1 for an aerial photograph of the reservoir, and Figure 2 which shows the structure in cross section.

### **Impact of the 22 February and 13 June 2011 Earthquakes**

The 22 February 2011 earthquake resulted in widespread destruction, and loss of life, in the Christchurch region. This included collapse of buildings or damage rendering them unsafe for occupation; land damage due to liquefaction, slope instability and rock fall; and damage to services infrastructure, including power, water and wastewater.

Detailed inspections of the Huntsbury No 1 reservoir, pipework and pump station were carried out in March 2011, followed by seismic strength and risk assessments. In summary damage sustained included a broken inlet/outlet pipe flanged connection, extensive dislocation and cracking of floor slabs, cracking of the roof slab and some movement at wall joints adjacent the corners of the structure. The associated pump station had been damaged beyond repair.

It is estimated loss of the stored water occurred over a period of several hours, but due to damage to the level sensing equipment no record of this is available.

The floor consisted of two layers of reinforced concrete slabs. The construction joints in the upper slabs were offset from those in the lower slabs. The practice was followed in the 1950's with the design objective being to increase the potential leak path in the event of localised failure of the sealed joints in the upper slab. The slabs were reinforced but there was no continuity of reinforcement across the joints.

The slabs cracked extensively to the point of rupturing the reinforcing with the concentration

of damage being in an approximately 20 to 30 metre wide diagonal strip across the reservoir. Refer to Figures 3 and 4.

At the time there was considerable concern in the local community about potential land damage caused by leakage from the reservoir. The reservoir is sited on material of volcanic origin, including old basalt (lava) flows with extensive fissures. In addition to the cracks in the floor, the main outlet valve was found to be in a partially open position which would have allowed water to flow out via damaged reticulation pipework in the city.

It is likely that leakage occurred both through the floor and via the outlet pipe.

The reinforced concrete roof exhibited a similar pattern of damage to the floor. This included extensive cracking and broken concrete at construction joints. However the roof structure remained intact due to the continuity of reinforcement through all joints.

The reinforced concrete walls experienced little damage apart from dislocation of vertical wall joints at the north west and south east corners.

In addition to visual inspections, the reservoir was surveyed for level and position, and a series of shallow boreholes were drilled through the floor to confirm founding conditions.

As assessment on options for repair and replacement were being made, a further earthquake on 13 June 2011 caused rupture in the roads adjacent the reservoir, with vertical and horizontal displacements occurring across a plan strip which coincided with the damaged floor and roof sections in the reservoir. It was suspected that a "shear zone" may be present under the reservoir, which allowed relative movements of the ground either side of it. This was subsequently confirmed by survey.

Geological investigations were undertaken comprising inclined boreholes which confirmed the presence of the shear zone (refer to Figure 1). Inspection of the borehole material revealed interfaces where rock to rock faces had slid across each other and others where rock elements were separated by softer

materials. It was estimated by the geologist who peer reviewed the findings that the last movement of this shear zone was in the order of 15,000 years ago.

The inlet/outlet pipe to the reservoir traversed the adjacent road, Huntsbury Avenue, via a tunnel. Inspection of the tunnel revealed collapsed roof sections with the fallen material deposited on top of the concrete lined mild steel pipe.

A flanged connection to the main isolation valve at one end of the tunnel had also failed. It was a flat plate flange with a single fillet weld to the outside of the pipe.

The structure of a pump station alongside the reservoir had moved differentially to the reservoir and required demolition due to the extent of damage.

## Design

The existing reservoir structural system for retaining water loads comprised walls supported vertically and horizontally at the base by a reinforced concrete foundation keyed into the ground, and horizontally at the top of the wall by the roof. The roof was supported by the perimeter walls and internal reinforced concrete columns. Figure 2 show the structure in cross-section. Seismic loads due to the contents and structure were transferred at roof level by the roof slab in diaphragm action to the walls.

Following confirmation of the shear zone, predicted future horizontal and vertical movements across it were 100 to 150mm in 20 to 50mm increments.

Accommodation of these predicted horizontal and vertical movements, inducing racking of the reservoir, was not considered feasible using the existing structural system.

In addition to the shear zone, the other key factors influencing design decisions at the time were the desired storage capacity on the site and the timeframe. Also considered was a new site, but no suitable option was identified.

The selected solution comprised two trapezoidal plan shaped reservoirs either side

of the shear zone (refer figure 1). The design required a new floor slab overlaid on the existing concrete slab, a new reinforced concrete foundation and walls adjacent the shear zone, re-use of the existing perimeter walls of the reservoir, and a new reinforced concrete roof. The existing roof column supports were also reused. The new roof slab was designed to allow a crane to operate on it during construction.

Insofar as watertightness provisions were concerned, joints in the floor slabs, slab to column footings and slab to wall base incorporated a combination of backstop type PVC waterstops with welded joints and expanding strip type waterstops cast into the concrete. Vertical joints in the new wall had two lines of expanding strip type waterstops in each joint. The objectives were to provide two lines of defence against leakage, and to minimise any exposed jointing materials, either sealant in rebate type or bandage, as replacement of these is a costly and time consuming maintenance activity. The existing wall joints were the only exception to this where a bandage type material was the most practicable option.

The new roof slab was overlaid with a fibreglass reinforced PVC sheet membrane to avoid leakage into the reservoir potentially contaminating the contents. Cracked concrete, particularly in thin roof toppings, was a common problem post-earthquake in Christchurch.

The structure itself was designed in accordance with the New Zealand water retaining structures standard. There was an increase of approximately 50% on the seismic load adopted for structures in Christchurch following the earthquake.

Detailing of the refurbished structure was designed to be resilient, in particular to avoid shear type failures. Lack of capacity at wall to roof joints was a common mode of failure in reservoirs in Christchurch.

Resilience of the pipework was also a key consideration. Each reservoir has an inlet/outlet pipe branch connected to a common inlet/outlet pipe. The inlet/outlet pipe is installed below the reservoir floor.

Immediately outside each reservoir there is an electrically actuated isolation valve which is closed in the event of an earthquake (via a signal from a seismic sensor device), a manual isolation valve, a flexible bellows and thereafter butt welded PE pipe traverses the shear zone and connects to the common inlet/outlet pipe section.

The philosophy used in the valving arrangement is that it is essential to be able to isolate the reservoir, and that the reservoir pipe stub must connect rigidly to the reservoir so that the chance of leakage is minimal. The seismically actuated valve is provided so that stored water is retained in the event of an earthquake thereby preventing reservoir drainage through broken reticulation pipework. The bellows type coupling in association with the PE pipe provides flexibility and minimises potential loads being transferred to the reservoir pipe stub.

There was a chamber constructed around the valve pipework spool. This was cantilevered off the main reservoir structure so that it acts structurally with the reservoir.

The existing inlet/outlet pipe in the tunnel under Huntsbury Avenue was pressure tested to determine its suitability for future use. It proved to be intact so was reused. The void between the outside of the pipe and the tunnel was filled with foam concrete to protect the pipe from further dislodging of material from the roof of the tunnel, and to provide some cushioning in the event of further movements within the shear zone.

Christchurch City Council had concluded that a reduced storage capacity was acceptable and a figure in the order of 15,000 cubic metres was adopted as a target. Some of this needed to be in place by December 2011 to enable the Council to accommodate the summer period demand.

### **Construction**

The following factors influenced the choice of construction methodology for the stage 1 reservoir:

- Restricted site access.

- The poor environment within the reservoir (confined space).
- The restricted space between columns in the reservoir.
- The hazard of falling debris from the damaged roof.
- Future earthquakes.

The most challenging activity was the construction of the new wall at 8000mm high by 600mm thick. The chosen methodology involved designing and constructing a new roof overlaid on the existing roof so that a mobile crane could operate at this level. Progressive cutting of the existing roof slab was carried out to allow crane placement of reinforcement, formwork and concrete into the new wall section. This methodology maximised the work that could be done outside the reservoir and proved very successful. Refer to Figure 5.

The ongoing nature of the earthquakes in Christchurch required engineering and construction judgement in assessing structural capacity during all stages of the methodology. The programme needed to accommodate the connection of sections of the new roof slab to the new wall prior to removing further slab sections.

The interior of the reservoir was a daunting place in which to work. Following earthquakes, construction staff were noticeably concerned to be working within a damaged structure. Mitigation measures such as removing loose concrete from the underside of the roof were undertaken and construction proceeded without incident.

Working conditions were not easy during stage 1 and it is a tribute to the construction staff who worked diligently to complete construction on time.

Construction of a new pump station proceeded in parallel with stage 1. This was commissioned in November 2011 and allowed water to be pumped to areas above the zone served by Huntsbury Reservoir.

The stage 2 reservoir construction was much simpler as the superstructure of the middle section of the existing reservoir was able to be demolished. This allowed mobile cranes to

operate at reservoir floor level in the area between the stage 1 and 2 reservoirs.

### **Management and Operation**

The relationship between Christchurch City Council, Fulton Hogan and Beca on earthquake repair works was established following the September 2010 earthquake. This proved valuable in responding to the subsequent earthquake events that took Huntsbury reservoir out of operation.

It is also worthwhile mentioning working conditions in Christchurch in 2011. The Council had relocated to temporary facilities throughout the city, with Huntsbury reservoir meetings taking place at a converted suburban library. Beca staff had similarly relocated to a motel. Fulton Hogan resources were heavily involved in stabilising infrastructure works on an urgent basis. Some staff also experienced damage to their residences.

The team however responded well to the challenge. Perhaps most significantly the Council was able to make key decisions without delay, which meant design and construction planning could proceed with confidence.

In addition Council staff communicated regularly and in some detail with the community residing in the reservoir area. People are naturally concerned and anxious to know what is going on, and the Council staff put significant effort into keeping them informed.

In short there was a team where each individual was clear on his or her responsibilities, and everyone had confidence that others would undertake their action points.

Clearly some flexibility was required in this situation. The June 2011 earthquake was discouraging in that it damaged repair works that had been or were in the process of being undertaken on infrastructure. In the case of Huntsbury reservoir this earthquake caused a rethink of the design and it took some weeks to define the extents of the shear zone, and hence reservoir plan shapes. Drawings were produced to suit procurement and construction planning needs.

The flexibility referred to above was required by all contributors to the project – the Council, material suppliers, designers, constructors, the local community and the water users of Christchurch.

A significant benefit to the local area is the development of a landscaped zone accessible to the public between the two reservoirs. It is envisaged this will be well utilised as it is a sheltered area.

Re-use of significant portions of the existing structure both as reservoirs and as retaining walls for the landscaped area is also worthy of note.

### **Results/Outcomes**

Construction of the stage 1 reservoir and pump station commenced in August 2011 and these facilities were commissioned in December 2011.

The stage 2 reservoir was commissioned in November 2012, and landscaping works were completed during 2013.

### **Conclusion**

This project was a reminder to all involved of the need for teamwork, prompt decision making, astute risk assessment and consultation with the community in reconstruction of a significant water infrastructure facility following severe earthquake damage.

It emphasised the need for strength and resilience in such facilities, and the attention to detailing in design and construction that this requires.

Looking forward to future reservoirs, the Huntsbury Reservoir performance highlighted the durability of concrete (as demonstrated by the ability to reuse existing walls), the importance of the continuity of reinforcing through all joints, the need for strength in structure and pipework connections, provision of manual and seismically triggered isolation valves and flexible, restrained joint in-ground pipework in areas subject to ground movement.

It is also emphasised to operators and users of the importance of potable water availability post-earthquake, and how easily this can be lost through lack of resilience.

### **Author Biography and Photograph**



Dennis Hunt is a design manager and structural engineer at Beca Limited. He has lead design teams on infrastructure projects covering water, wastewater, power and roading sectors.

Major water industry projects include the upgrade of the \$450m Mangere Wastewater Plant (Project Manukau), the \$100m Waikato Water Treatment Plant and Pipeline, and the \$250m Hunua 4 pipeline. Dennis was the prime author of this paper which was reviewed by Mark Christison of Christchurch City Council and Robert Clifton of Fulton Hogan Limited.

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*Figure 1: Huntsbury No 1 reservoir plan*



*Figure 2: Huntsbury No 1 stage 2 reservoir - under construction*



*Figure 3: Dislocated Floor Slab Joint*



*Figure 4: Crack in Floor Slab*



*Figure 5: New Floor and Wall Sections under construction*