DAMAGE TO POTABLE WATER RESERVOIRS IN THE DARFIELD EARTHQUAKE

Robert A. Davey [1]

SUMMARY

The M_w 7.1 earthquake that struck 40 km west of Christchurch on 4 September 2010 provided a good test of the robustness of the water storage and distribution system of one of our major cities to provide a secure supply of water.

In this paper we present damage data from inspections of 54 reservoirs that were undertaken on behalf of Christchurch City Council and other owners. These included concrete, steel and timber tanks, five of which collapsed and four severely damaged.

INTRODUCTION

Shortly following the M_w 7.1 Darfield earthquake that struck 40 km west of Christchurch on 4 September 2010, inspections were made of potable water storage reservoirs in Christchurch City, in Paparua to the West of Christchurch and Ashburton to the South. The purpose of the inspections was to assess damage levels and make preliminary estimates of the cost of repair.

The types of tanks inspected included concrete, steel and timber tanks. Associated pipework, valves, pumps, controls and instruments, housing, access roads, etc were included in the inspections.

In this paper we present the results of the inspections and make preliminary observations on the performance of the reservoirs. We are presently evaluating the performance of the tanks in more detail and propose to present the results of this investigation in due course.

CONCRETE TANKS

A total of 44 concrete tanks at 34 locations, all owned by Christchurch City Council were inspected. Most of the tanks are of circular concrete construction, a few are rectangular concrete. Examples of the types of construction are shown in Figures 1 to 3.

Figure 1: Reinforced concrete tank.

Figure 2: Large prestressed concrete tank.

Figure 3: Rectangular tank.

There is a wide range of ages, with a large proportion having been constructed prior to the first publication of the standard for design of concrete liquid retaining structures NZS 3106 in 1986 [1] and subsequent revision in 2009 [2]. The reservoir assets appeared to be in very good condition and well maintained. The tanks, buildings and other components are robustly constructed with attention to seismic detailing. There is evidence of recent seismic retrofitting work for example to tie roof slabs to walls on a number of tanks.

[1] *Opus International Consultants, Wellington, New Zealand.*

Three of the reservoirs are located in the deep alluvial soils of the Christchurch basin, the remainder are located on the Port Hills on rock.

The condition grading system and the numbers of reservoirs assessed to be in each grade are shown in shown in Table 1.

Table 1: Reservoir asset condition grading

Condition Grade	Description	Number in Grade
1	No repairs required.	38
2	Minor repairs required.	3
3	Repairs required but asset still serviceable.	1
4	Substantial repairs required in short term, asset barely serviceable.	1
5	Major repairs or replacement required to restore serviceability.	1

Thirty-eight, or 86% of the tanks had no discernable damage that could be attributed to the earthquake. Only two tanks had serious damage, both are located on the alluvial plain on the western side of Christchurch and both sustained roof damage. One of these sustained damage to the junction of the roof and wall (Condition Grade 4) apparently because the concrete nib at the top of the wall could not withstand the inertia load applied by the roof.

The other tank suffered partial collapse of the roof caused by buoyancy forces from the earthquake-generated convective ("sloshing") wave causing the slabs to be lifted off the supporting walls and fractured when they impacted down again (Figure 4).

Figure 4: Reservoir roof damaged by convective wave.

TIMBER TANKS

Four timber tanks were inspected, three located on the Port Hills and owned by Christchurch City Council and one at Paparua to the West of Christchurch.

Two of the Council tanks leaked following the earthquake, while one remained functional. The Paparua tank collapsed.

Timber tanks are typically not anchored to their foundations and the system relies upon base-isolation with the tank wall sliding on the foundation to control the forces in the structure to a level that the timber stave walls can support by inter-stave friction. Figure 5 shows two tanks that have exhibited base-isolation response, however the wall displacements have apparently caused the liners to rupture and the reservoirs to leak.

Figure 5: Timber tanks with ruptured liners.

The collapsed tank is shown in Figure 6.

Figure 6: Collapsed timber tank.

STEEL TANKS

All of the inspected steel tanks were bolted steel construction with a PVC or similar material liner. The tanks were secured to a concrete foundation slab with anchor bolts.

Six tanks were inspected, four of which failed at the anchor bolts. The four damaged tanks are located in Paparua. The undamaged tanks are located in Rakaia which is a similar distance from the earthquake epicentre as Paparua. The Rakaia tanks are smaller than those at Paparua but have a greater number of and larger anchor bolts explaining why they did not fail.

An example of a failed steel tank is shown in Figure 7. Fractured anchor bolts can be seen in Figure 8.

Figure 7: Damaged bolted steel tank.

Figure 8: Fractured anchor bolts.

There have been reports of similar failures of other bolted steel tanks in the region.

All of the steel tanks inspected were designed prior to the publication of the 2009 version of the New Zealand Society for Earthquake Engineering guidelines for the seismic design of storage tanks [3].

CONCLUSIONS

Christchurch City's concrete reservoirs performed very well in the Darfield earthquake, with no instances of loss of stored contents due to leakage, fracture of pipes or valve failure. In the majority of cases there was no discernable damage that could be attributed to the earthquake shaking.

Severe damage to the roof of one concrete tank does highlight the importance of avoiding or allowing for uplift pressures from the sloshing wave in the roof design.

Timber tanks performed poorly, raising questions about the ability of the tank liners (and possibly inlet and overflow pipes) to withstand the displacements of the tank wall relative to foundation that are a fundamental feature of the system.

Steel tanks also performed poorly, raising questions about the methodology and criteria used for design of the anchor bolts in particular.

The reservoir damage data from the Darfield earthquake, along with the earthquake records available from Geonet, provide an excellent opportunity to further investigate the vulnerability of reservoirs to earthquake damage, to assess the adequacy of current earthquake design methodologies and criteria, and to make improvements if necessary.

REFERENCES

1. NZS 3106:1986, "Concrete structures for the storage of liquids", *Standards New Zealand*.
2. NZS 3106:2009, "Design of concrete structures for the storage of liquids", *Standards New Zealand*.
3. NZSEE, (2009), "Seismic design of storage tanks", *New Zealand Society for Earthquake Engineering*.