WELLINGTON REGION'S RESERVOIR SEISMIC UPGRADE STANDARDS

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ABSTRACT

This paper outlines the technical basis to reservoir seismic resilience work in the Wellington region. Following an earthquake the Wellington region will rely on reservoirs to initially provide safe drinking water. For this reason reservoirs need to be seismically resilient. As part of region's ongoing seismic resilience work Wellington Water manages the capex upgrade work to provide seismic resilience reservoir systems. That system includes the elements of: reservoir structure, geotechnical considerations, pipework, control huts, and control equipment.

Wellington Water manages the water assets for five Councils: Wellington, Hutt, Porirua, Upper Hutt, and Greater Wellington Regional. Within the water supply system there are currently some 140 reservoirs servicing a population of around 390,000 people. The reservoir age range is from new to over hundred years old. Nominally three to four reservoirs are upgraded across the region each year and a new reservoir constructed every three to five years.

This paper covers retrofit elements that are assessed and upgraded to provide a seismic resilient reservoir system including walls – hoop strength, roof uplift, floor slab capacity, overturning, roof capacity, and high level geotechnical considerations.

Existing reservoirs may not have been designed to current standards. Consideration is given to the retrofit seismic resilience classes that have been developed. Also considered are the adopted standards for new reservoirs.

KEYWORDS

Resilience, reservoir, seismic, pipework, retrofit, upgrade

1 INTRODUCTION

Wellington Water is a shared service, council-controlled organisation jointly owned by the Hutt, Porirua, Upper Hutt and Wellington city councils, and Greater Wellington regional council. It manages the three water networks (drinking water, stormwater, and wastewater) on behalf of our client councils and provides advice on how best to deliver the three water services. Wellington Water is implementing a regional approach to planning, operating, and managing its water networks. To achieve this it has committed to regional priorities, one of which is to improve the resilience of the water supply for the region.

Provision of a potable water supply is essential to maintaining public health. On a day to day basis, some 140 million litres of potable water passes through Wellington Water's intake, treatment, and distribution network for consumption; supporting the local and national economy. Water is collected and treated by Wellington Water before delivery via the bulk water network to the cities. Sources of Wellington's drinking water include the Hutt River, Waiwhetu Aquifer, Orongorongo River, and Wainuiomata River. A natural disaster such as a significant earthquake in the region may severely compromise the water supply network, affecting both quality and the quantity of water supplied. A reduction in water quality can introduce outbreaks of disease affecting public health and placing significant pressure on scarce medical resources. A reduction in the quantity of water supplied can further exacerbate public health issues and fundamentally threaten life immediately following the event.

Reservoirs provide a reliable source of stored safe drinking water to the region. They also provide operational, fire fighting, and emergency water storage. Typically reservoirs hold around one to two days storage under normal use. Following an earthquake the Wellington region will rely on reservoirs to initially provide safe drinking water. For this reason reservoirs need to be seismically resilient.

The seismic resilience of a reservoir is a measure of its ability to retain water and become operable shortly after an earthquake.

This paper is to provide background to reservoir seismic resilience work (new and retrofits) in the Wellington region.

2 SEISMIC RESILIENCE AND STANDARDS

To meet requirements of the New Zealand Building Code reservoirs are designed in accordance with the following New Zealand Standards (NZS):

- NZS 3106:2009 Design of concrete structures for the storage of liquids
- AS/NZS 1170.0:2002 Structural Design Actions Part 0: General principles
- NZS 1170.5:2004 Structural Design Actions Part 5: Earthquake actions – New Zealand

Photograph 1: Seismic upgrade of Carmichael reservoir (7.8ML).

The 1986 Design of Concrete Structures for the Storage of Liquids NZS 3106 was updated in 2009. That update covered four main areas including: serviceability limit state SLS2 loadings, and ultimate limit state loadings ULS, a new liquid tightness classification, procedures on determining crack widths, and alignment with the then 2009 NZSEE draft recommendations for Seismic Design of Storage Tanks.

2.1 IMPORTANCE LEVEL

The ability of a structure to withstand seismic loads depends on its importance level, as defined by the AS/NZS 1170.0:2002. Reservoirs in Wellington are classified as importance level 4 (IL4) structures as they have a special post-disaster function of storing safe drinking water.

There are five importance levels in the standard based around consequences of failure. IL1 is for structures that includes structures less than $30m^2$ such as farm buildings and fences. IL2 is for structures including single family dwellings and car parking buildings. IL3 is for structures including those that as a whole may contain people in crowds or contents of high value to the community or pose risks to people in crowds. IL4 is for structures that provide a special post-disaster function. IL5 is for special structures outside the scope of the standard such as major dams or extreme hazard facilities.

2.2 SERVICEABILITY LIMIT STATE AND ULTIMATE LIMIT STATE

Engineers design reservoirs to perform to a certain standard for two different scenarios. These are defined as the 'serviceability limit state 2' (SLS2) and 'ultimate limit state' (ULS). SLS2 for reservoirs is defined as remaining operable immediately following a seismic event and has been interpreted as minimal loss of water and to supply water with minimal or no repairs immediately after an earthquake.

New reservoirs are designed for a 100 year working life and designed to IL4 for an event with return periods of 1,000 year SLS2 and 2,500 year ULS and the reservoir is to retain water under both events. Seismically upgraded reservoirs (assuming a working life of 50yrs) are designed to IL4 for an event with return periods of at least 500 year SLS2 and 2,500 year ULS and are only required to retain water under the SLS2 scenario.

Seismic design loads used by engineers when designing reservoirs are based on earthquake return periods. The return period determines the maximum strength earthquake likely to occur over that time and varies across New Zealand. A common public misconception is that an earthquake 'return period' means only one seismic event of that magnitude will occur over that time, however it is actually the 'likelihood'; for example Wellington may experience several '1 in 500 year' seismic events in any given period.

AS/NZS 1170.0:2002 indicates the SLS2 return period for a 50 year working life but not for a 100 year working life. The probability of exceedance over a 50 year design working life for IL4 structures with an SLS2 of 500 years is 18% and an ULS of 2,500 years is 4%. An IL4 100 year working life SLS2 return period of 1,000 years could be argued based on providing the same 10% probability of exceedance of that for an IL4 year working life.

The ULS for reservoirs means they may suffer some damage following a 1 in 2,500 year seismic event, but they will not collapse or cause harm to people. They may require repair following the earthquake. Non-critical structures (surplus storage or redundant or non-essential) can adopt a lower standard.

2.2.1 RESILIENCE CLASSES

Standards are progressively updated over time and existing reservoirs may not have been designed to current standards. To assess existing circular reservoirs seismic resilience classes were developed by Opus International Consultants. A hoop response performance class has been adopted both to assess the results and guide retrofit works. Classes range from A to D. Class A exceeded current minimum design standards for IL4 reservoirs. Class B had a hoop stress greater that 85% of that for ULS. Class C was less than 85% of ULS whereas Class D was for reservoirs with critical weaknesses such as inadequate floor wall joints or not assessed. This hoop performance class only relates to circular reservoirs and is not the same as new building standard percentage (%NBS) as used in the Building Code in relation to earthquake prone assessment.

2.2.2 REMEDIAL OPTIONS

A range of remedial options are available dependent on the upgrade required. The do nothing option accepting a lower seismic strength and continuing to use the reservoir for operational purposes is always an option to be considered. Maximum water levels can be lowered to reduce wall loadings or slosh on the reservoir roof. If levels are reduced then overflow levels within the reservoir may be lowered to ensure lower maximum levels cannot be exceeded. A common deficiency is the wall floor joint or wall roof joint requiring external jointing or internal ring beams. Wall hoop stress deficiency has been mitigated by carbon fibre wrapping, post tensioning or steel shells.

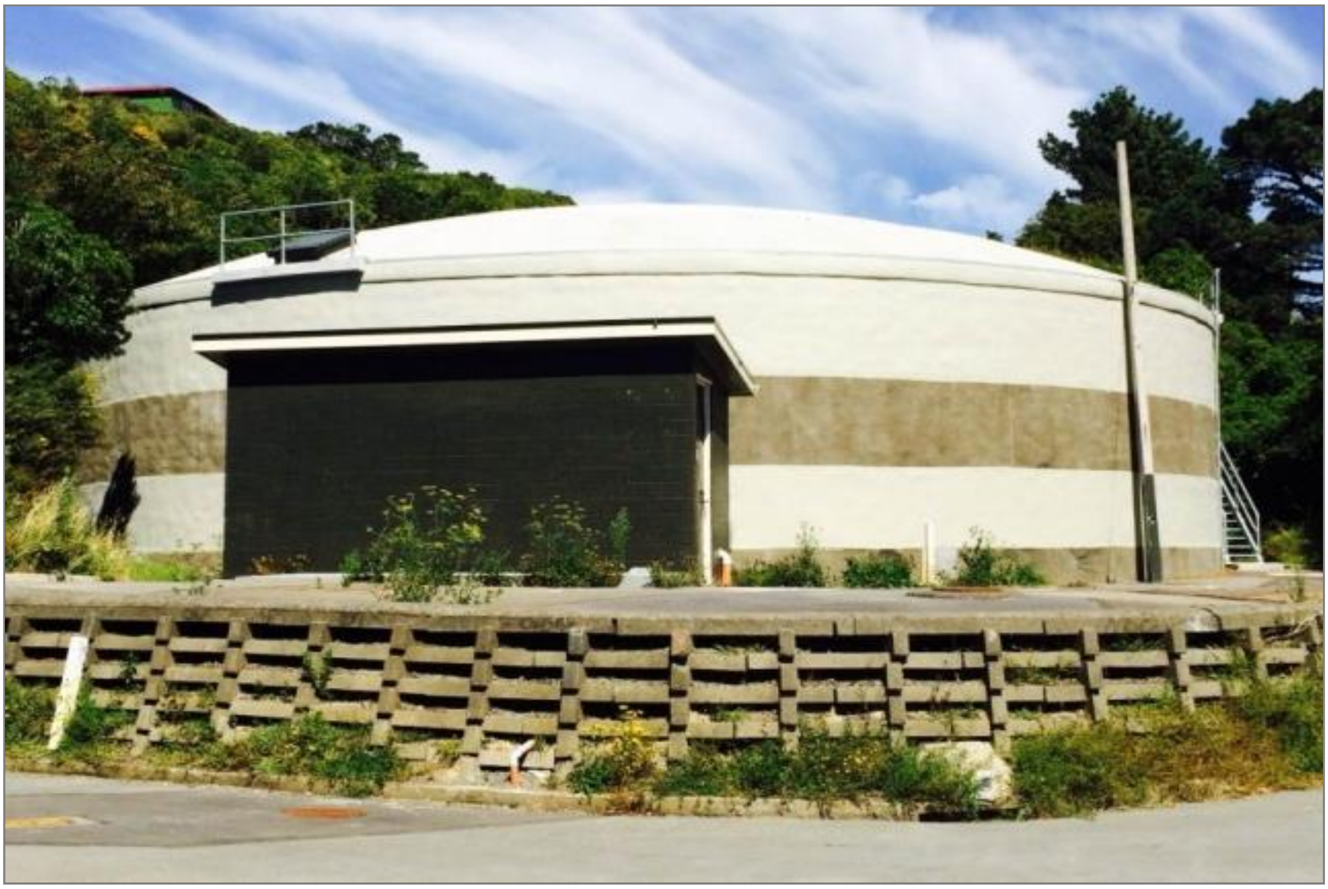
3 RESERVOIR SEISMIC RESILIENCE PROCESS

The objective of a seismic resilient reservoir system is to retain water within the reservoir after a major seismic event and minimise damage requiring repair during the recovery phase. The system elements considered are the:

1. reservoir structure,
2. geotechnical assessment,
3. pipework (including inlet and outlet protection),
4. control huts, and
5. control equipment.

Historically the focus of reservoir seismic resilience was around the reservoir structure and inlet/outlet protection. Further elements were subsequently introduced to consider the reservoir as a system.

3.1 RESERVOIR STRUCTURE



Photograph 2: Recent seismic upgrade works at Johnsonville reservoir (2.3ML). Works included wrapping and roof strengthening

Around 1986 with the introduction of the Design of Concrete Structures for the Storage ofLliquids standard NZS3106, reservoir design made a significant leap forward. Seismic assessment for reservoirs is a priority for pre 1986 structures.

For post 1986, structures assessments are a lower priority. Prioritisation of reservoirs is generally by: current seismic performance, age, remaining life, size, criticality, operational, and constructability issues. Subject to any subsequent assessment work post 1986 structures are assumed as classes B or greater.

Retrofit projects should incorporate an assessment of the existing capacity of certain elements for SLS2 and ULS, including (but not limited to): walls (hoop strength), roof uplift, floor slab capacity, overturning, roof capacity, and high level geotechnical walk over.

A risk based approach with engineering judgement is needed given the potential "steep rise" in cost that may exist if a rigid cut-off figure is set for retrofit works That is the difference between a reservoir just below and just above a rigid cut-off could be considerable with little benefit. Impact of water level is another factor more recently considered. Reservoirs operate to a maximum level of 95% and typically between 80 to 95%. The risk of changing water level must be weighed against rigid cut-off figures.

Wellington Water is working on behalf of the Councils to assess the performance of reservoirs across the Wellington Region and undertake upgrade or renewals where required. Upgrade works are targeted at achieving class B performance. Older reservoirs scheduled for replacement or some reservoirs such as small tanks (e.g. 25m^3 ferro-cement tanks) are generally not considered for assessment. These are classified as Class D.

3.2 GEOTECHNICAL ASSSEMENT

A brief walkover inspection and geotechnical assessment is carried out. The objective is to assess the seismic performance of each site by considering potential slope failures, potential loss of support to reservoirs and control sheds and potential damage from falling debris. A desktop assessment is then carried out. No subsurface investigations or slop stability analyses modelled unless these are recommended as beneficial for further investigation stages.

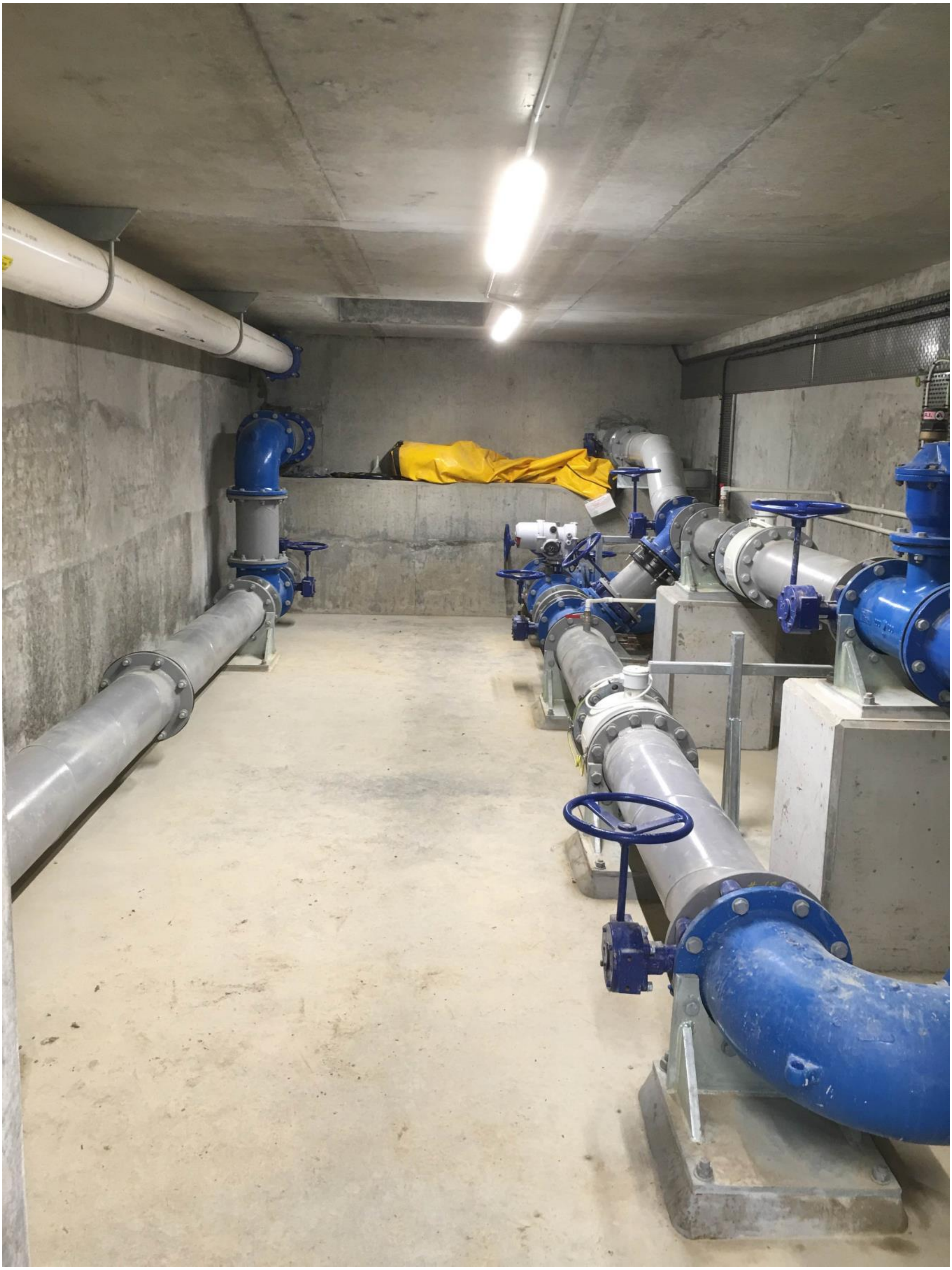
3.3 PIPEWORK

Reservoir pipework may be vulnerable under seismic loading and may cause loss of water. Ground movement and liquefaction can cause damage to water pipes, including breakages and pipe bursts. Reservoirs being at a higher elevation are located on hills are therefore not subjected to liquefaction in the Wellington Region.

Water loss may also come from inlet, outlet, scour, and/or overflow pipe failure. This may be inside the reservoir where pipe up-stands are used and/or outside the reservoir structure. Pipe materials including brittle materials such as asbestos cement or ductile iron may fail. Jointing systems that do not provide both flexibility and restraint may cause fail. Depending on ground conditions there may be radial or longitudinal displacement along the pipe. Many coupling types are susceptible to pull-out of the pipe.

All reservoir pipework elements (valve, fittings, pipe material, and couplings) are assessed to provide a resilient system. All pipework (pipe and joints) within and outside the reservoir are assessed. Inlet and outlet protection is put in place. Inlet protection can be by way of standpipes within the reservoirs and/or non-return valves and/or auto-shut valves. Outlet protection is generally by way of auto-shut valves. A resilient system is put in place between the inlet isolating valve, scour valve, and auto-shut valve. Any up-stands are upgraded and suitably braced.

Auto-shut valves are installed on reservoir inlets where there is no non-return valve or up-stand and on reservoir outlets. The valves are designed to close on high flow and may be triggered by earthquake triggers and/or high flow. The objectives are to minimise: water loss from pipe break (burst), water loss from pipe failure associated with earthquakes, and minimise unnecessary auto closing of valves. Flows are normally established by magnetic flow meters at the site.

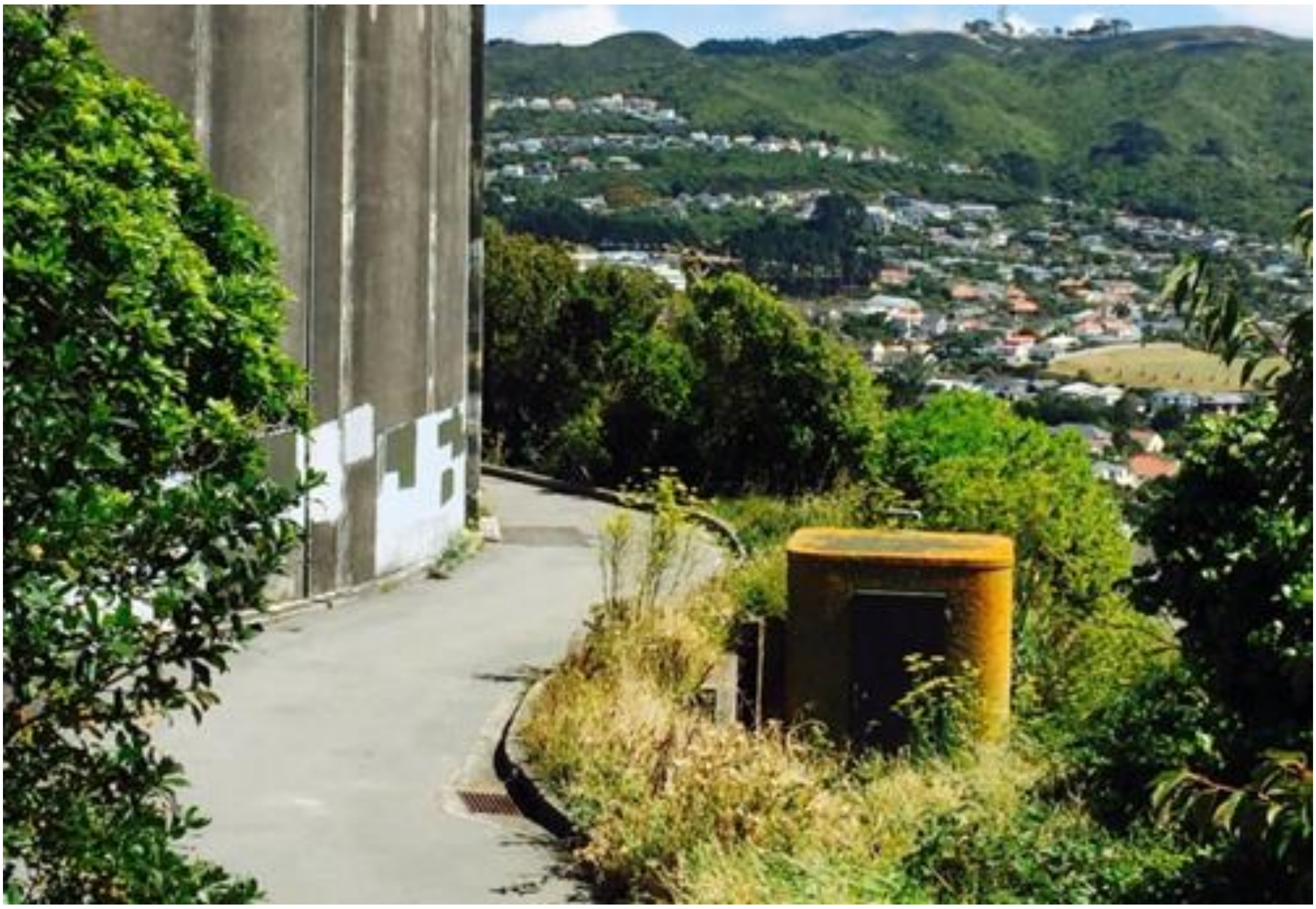


Photograph 3: Melrose reservoir (2.2ML) tunnel (2016)

A three set point trigger system is adopted with the first trigger set at design flow, second trigger at a flow less than the pipe break flow (say 30 l/s less), and third trigger set at pipe break flow or earthquake trigger with high flow within one hour of an earthquake trigger. An assessment is made as to the likely flow from a pipe break at say 800 m (depends on topography, etc) from the reservoir and taking into account peak flows and fire flows. Trigger one sends a SMS alarm to the operations contractor if the trigger value has been met for more than 30 seconds. Trigger two sends a SMS in a similar manner to trigger one. When trigger three is held for more than 30 seconds an alarm is raised and the valve begins to close. The programme to control the valve is held in the RTU at site so the valve will be close even in loss of communication to and from the site.

4 CONTROL HUTS

The reservoir control system is often housed within control huts, valve chambers, or reservoir tunnels. Control huts are separate to the reservoir and are often known as TDI huts where TDI stands for telephone depth instrument. They are usually self-contained huts of two metres in diameter or 2.4 metres square. A resilient hut is considered as having a structural performance of at least Class B, medium or better geotechnical risk with all equipment seismically resilient.



Photograph 4: Typical TDI hut Johnsonville, Wellington

Generally there is a lack of as-built information as to reinforcing detailing. At the time of writing intrusive testing was being arranged to ascertain reinforcing size and spacing across a range of hut types. Of concern are overall sliding, uplift resistance, performance of base connections, and the potential damage to equipment cabling of any movements.

5 CONTROL EQUIPMENT

Equipment used to control water in and out of the reservoir either locally or remotely. Equipment if, damaged or it fails, may cause loss of water from the reservoir in a seismic event. For instance, if the auto-shut valve fails to operate and a main has burst the reservoir will drain. Huts have a range of control equipment mounted directly to walls or supported from brackets. That equipment may include: flow meter controls, auto-shut valve controls, battery packs, reservoir level controls, telemetry communication equipment, earthquake triggers, electricity meters, computer equipment, power distribution, and control boards, sample taps, lighting, and pipework (generally small diameter).

Equipment items of interest for restraining includes: fixing of battery racks with wrap round restraints and spacers to prevent damage; fitting of latching mechanisms for equipment that may slide out such as data cabinets; fixing of earthquake triggers to their plinths in accordance with manufacturer's instructions; restraint of all components using straps, bars, and bolts to resist IL4 accelerations; allowance of displacement of cables, ducting and conduits, and allowance for building displacement for cables, ducting and conduits.

6 CONCLUSIONS

Providing a resilient reservoir system requires more than just assessing and upgrading the structure. Other elements such as geotechnical considerations, inlet protection, outlet protection, pipework, control equipment, and control huts must also be considered and if need be upgraded to reduce the risk of reservoir loss of water. Some of these elements are low capital cost but very important. The attention to detail for seismic resilience work is imperative.

The ability of a structure to withstand seismic loads depends on its importance level, as defined by the AS/NZS 1170.0:2002. New reservoirs in Wellington are classified as IL4 structures with a working life of 100 years as they have a special post-disaster function of storing safe drinking water. For existing structures care must be taking considering criticality and costs with the objective being of holding water (SLS2) after a IL 4 event considering the remaining life if the structure.

ACKNOWLEDGEMENTS

We wish to acknowledge and thank Opus International Consultants, Wellington Structures for many years of input and guidance with the associated structural understanding.

REFERENCES

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