Quantifying Seismic Strengthening in Wellington's Commercial Building Stock

2013 NZSEE Conference

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ABSTRACT: Wellington City Council (WCC) has been actively implementing an "Earthquake-Prone Buildings" policy since 2006. This requires that buildings assessed at less than 34% of New Building Standard (NBS) are upgraded to be at least above 34%NBS. However since the Canterbury earthquakes of 2010-11, tenant requirements and insurance costs, have resulted in many buildings being strengthened from below 34% NBS to much higher levels than 34%NBS, and buildings less than 100%NBS and particularly below 70%NBS being strengthened to at least 70%NBS. WCC captures data on buildings that come off the "earthquake prone register", as they are strengthened but other details are not collated. This study will be completed by the end of February and will generate this data from building consent records on the level of strengthening above 34%NBS, strengthening of buildings assessed to be above 34%NBS. Other information will also be collated, in particular project staging, building use, building age, structural type, and methods and materials used for strengthening. The magnitude of the increase in number of buildings strengthened, or to be strengthened, and increase levels of strengthening in response to the Canterbury earthquake sequence will be clearly evident. The information, which does not appear to have been collated elsewhere in New Zealand, will be used to determine market response to strengthening imperatives and to inform decisions by local and central government around possible incentives for earthquake strengthening. Information from Wellington is nationally significant due to the high probability of earthquake, and a substantial stock of commercial buildings.

1 INTRODUCTION

In New Zealand, and in particular Wellington there are a large number of older buildings that were built when knowledge of both earthquake hazards and design for earthquakes was more limited than it is at present. The two most significant historical changes occurred in the mid-1930s after the 1931 Hawkes Bay earthquake, and 1976, when the new loadings code, New Zealand Standard NZS4203, was introduced (SANZ 1976). Generally buildings designed and built after 1976 are expected to achieve at least 80% of New Building Standard (NBS), unless they have "critical structural weaknesses". These changes have improved the earthquake resistance of new buildings, however it does nothing for the earthquake resistance of older buildings. Prior to the enactment of the 1991 Building Act, some territorial authorities made attempts to improve the earthquake resistance of existing buildings in their area, with limited success, until the Building Act provided statutory requirements.

The 1991 Building Act (NZ Govt., 1991), Section 66 introduced the category of "Earthquake Prone Buildings". This category was limited to unreinforced masonry and unreinforced concrete buildings, and the level of performance was to a "moderate earthquake" that is, to resist a level of shaking of 50% of the load defined in NZS1900:Chapter 8;1965 (NZSI 1965), which in Wellington is of the order of a about a peak ground acceleration (PGA) of 0.12G, for a building of limited ductility (ductility factor of two). This provision gave Territorial Authorities the right to prevent access to the building, or to notify the owner and give a time frame for remedial works, or demolition. Although complicated by ductility factors, natural period of vibration for a building period and other provisions, this compares with a design PGA of about 0.5G for a new building with a ductility factor of two. Hence buildings strengthened to this level would have a capacity of about 20% NBS, or less if their ductility was less than 2.0. Residential buildings of 3 or fewer units or less than 3 storeys are exempt from these requirements.

Many buildings were strengthened to this minimum standard, but the bar was raised in 2004 with the New Building Act, which required Territorial Authorities to set out and implement a policy on Earthquake Prone Buildings. Wellington City Council has implemented a policy of requiring earthquake prone buildings to be strengthened over 10-20 years depending on their age and type of use (WCC 2009).

In 2005 the definition of a moderate earthquake was redefined as 33% of NBS for a new building on the same site by the Building (Specified Systems, Change the Use, and Earthquake-prone Buildings) Regulations 2005.

When a building undergoes a "Change of Use", for example from an office building to residential the 1991 Building Act required that buildings comply, with the current code for "…structural and fire rating behaviour…". This was frequently interpreted as structural behaviour only when related to fire, so in the 2004 Act it was reworded as "…structural performance, and fire-rating performance…", to clarify that it included general structural performance including earthquake resistance (Brookers 2013). This miss–interpretation meant that requirements to upgrade structural performance when a building underwent a Change of Use were not always enforced as rigorously as they should have been.

Obviously the significant earthquakes in Canterbury of 4th September 2010 and 22nd February 2011, have raised tenants, building owners and insurers level of awareness of earthquake risk. Insurers have substantially increased premiums or chosen not to cover "earthquake prone" buildings. Tenants have decided to relocate to buildings with better earthquake performance with some organisations stipulating minimum standards such as 70% NBS, and building owners have chosen to complete strengthening of their buildings, to respond to these issues and because their own awareness of the risks had increased. This study is intended to assess the magnitude of the increase in the rate of earthquake prone buildings being strengthened, any increase in the level of strengthening, and the rates of strengthening of buildings not deemed "earthquake prone", but less than 100%NBS.

It should be noted that this study refers to the Wellington City Council area, which reaches as far north as Tawa and Horokiwi, but does not include Porirua, Kapiti Coast or the Hutt Valley and further north. The term "earthquake prone buildings" is a legally defined term for buildings of less than 34% NBS.

1.1 **Wellington Building Stock**

Wellington City is the major population centre in New Zealand most likely to experience severe earthquakes. Due to the site of its Central Business District, constrained on one side by hills and the other side by harbours, multiple storey buildings were more common earlier in its history and a number survive today. With this combination of circumstances there is a significant proportion of the building stock that is earthquake prone. These pose a risk not only, to occupants, but also to users of adjacent streets and collapse into streets and roads may block access after an earthquake to evacuees, rescue personnel and other services. The number of "earthquake prone" building in Wellington is a moving target as new ones are identified, although this has now slowed down greatly, and others are removed from the register as they are strengthened and demolished. As at 1/1/12 there were 597 buildings on Wellington City Council's earthquake prone buildings list (WCC 2012), from a total of about 5100 pre-1976 buildings (Martin Jenkins 2012). With about 70% of buildings having been assessed on behalf of WCC using an Initial Engineering Procedure (IEP), the total number of earthquake prone buildings is likely to be around 900 buildings.

Many "earthquake prone buildings" are small in size, so numbers of buildings do not necessarily reflect the proportion of buildings that is earthquake prone.

1.2 Background to the Study

This study was initiated by Wellington City Council using Victoria University's Summer Scholarship programme, where students moving on to post-graduate study are employed to carry out research funded 50:50 by the sponsor and Victoria University. Data is recorded on individual building about any building work that has been carried out requiring consents, and the Earthquake Prone Building Register changes when buildings are strengthened or demolished. However any more detailed data was only captured in the Building Consents held on the individual property file, so the only tabulated information is whether buildings were strengthened from less than 34% NBS to more than 34% NBS.

More detailed compiled data was necessary to inform the Wellington City Council about the effectiveness of the Earthquake Prone Buildings Policy and can be used as part of on-going planning.

2 METHODOLOGY

The study goes back to 2007, when Building Consents as this is when Wellington City Council's current "Earthquake Prone Buildings" policy came into force. All non-residential building consents were analysed to see if earthquake strengthening work was carried out and 156 individual consents were identified. If the project involved earthquake strengthening, the following data was compiled into a spread sheet from information in each individual consent:-

- Date of consent
- Building Address and Identification
- Building Age
- Building use (Commercial, Education, Health, Industrial/Warehouse, Infrastructure, Public Use, or Residential, or combination thereof)
- Structure type (Material and type of lateral load resisting system)
- Number of floors
- Current level of strength (%NBS)
- Building consent number
- Strengthening construction techniques
- Strengthening stage (Stage of project in multistage strengthening project)
- Level of strengthening (%NBS)
- Building Floor Area (m^2)

This collated data can then be analysed to answer a number of questions including the following:

- What is the age gradation of buildings being strengthened?
- What is the usage of buildings being strengthened?
- Are more buildings being strengthened and if so is the rate increasing?
- Is there any indication that the two major earthquakes in Christchurch have affected the rate of strengthening?
- To what level are buildings being strengthened?
- Is there any indication that the two major earthquakes in Christchurch have affected the level of strengthening?
- Do the rates and levels of strengthening vary with the size (height and floor area) of buildings?

3 RESULTS

Firstly the results show the background to the sample, with Figure 1, showing the age gradation of buildings with consents for strengthening. The rate is relatively consistent for buildings built between 1920 and 1990, except for 1940s, which could be explained by the fact that construction was slow during World War II and the immediate post-war period. Fewer buildings were built in the late 19th and early 20th century and fewer have survived, explaining the reduced number of earlier buildings in the sample. More recent buildings, built in the 1990s and 2000s would be expected to achieve close to

100% NBS, so a decline in these two decades is expected. A surprising result is that there are more buildings in the 1980s, than the 1970s, when the "modern" loadings code NZS4203, was only introduced part way through the 1970s.

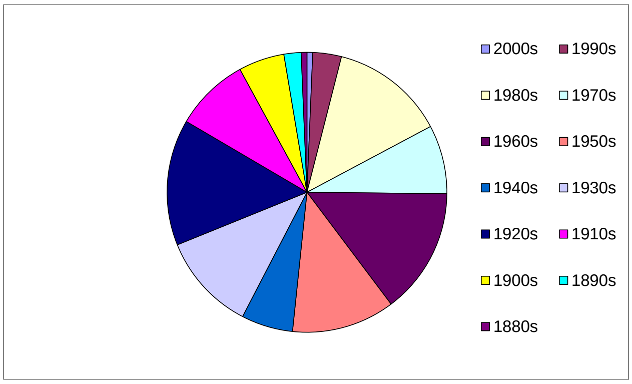

Figure 1. Age Gradation of Buildings with Consents for Strengthening

Figure 2 shows the use of buildings undergoing strengthening in Wellington City. The majority are commercial, with education and residential being the next two biggest groups, with few health, infrastructure and industrial properties.

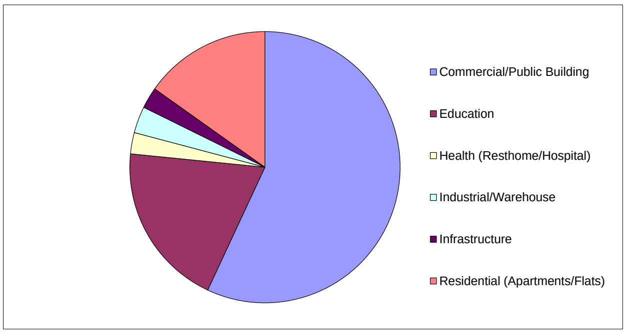

Figure 2. Use of Buildings with Consents for Strengthening

3.1 **Rates of Strengthening**

The change in the number of consents for strengthening is shown in Figure 3. The black line is a polynomial regression of the discrete numbers.

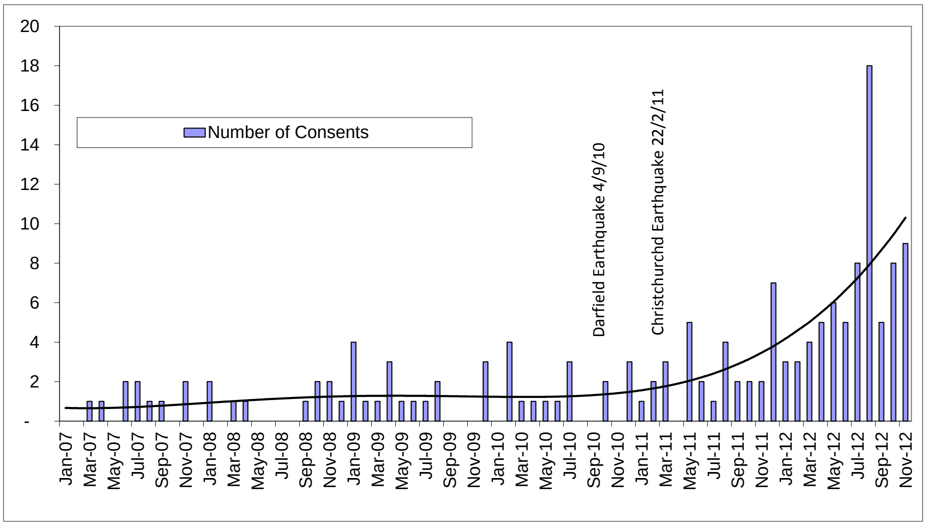

Figure 3, Rate of Consents Issued for Earthquake Strengthening

Wellington City Council enacted its Earthquake Prone Building Policy in May 2006. Numbers are steady, but low in 2007 and 2008, then increased by about two thirds in 2009 and 2010, almost doubled over the previous year in 2011, and more than doubled over the previous year in 2012. The timing of the two Canterbury Earthquakes is shown for comparison. As the timeframe for strengthening in the policy is between 15 and 20 years, for most buildings, the rapid increase cannot be explained by pending policy deadlines for strengthening, but can only be explained by the response to the Christchurch earthquakes. The trend in consents for strengthening based on floor area is less clear prior to 2011, but shows a large jump in 2012 (Figure 4.). It should be noted that data on consents is recorded, hence more than one consent can be recorded for a site, due to staging of a consent, more than one building on a site, or in some cases a building has been strengthened twice, one example being a building strengthened in 2007 and to a higher level in 2011. The numbers given in this paper refer to consents, not buildings, but less than 10% of the consents were multiple consents for the same property.

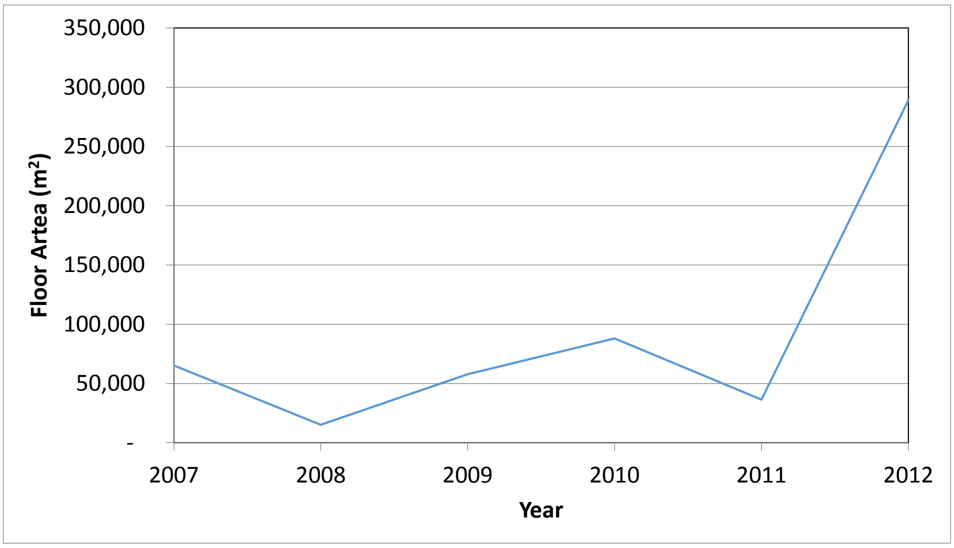

Figure 4, Rate of Consents Issued for Earthquake Strengthening by Floor Area

3.2 Levels of Strengthening

The overall increase in strength of buildings undergoing strengthening is shown in Figure 5.

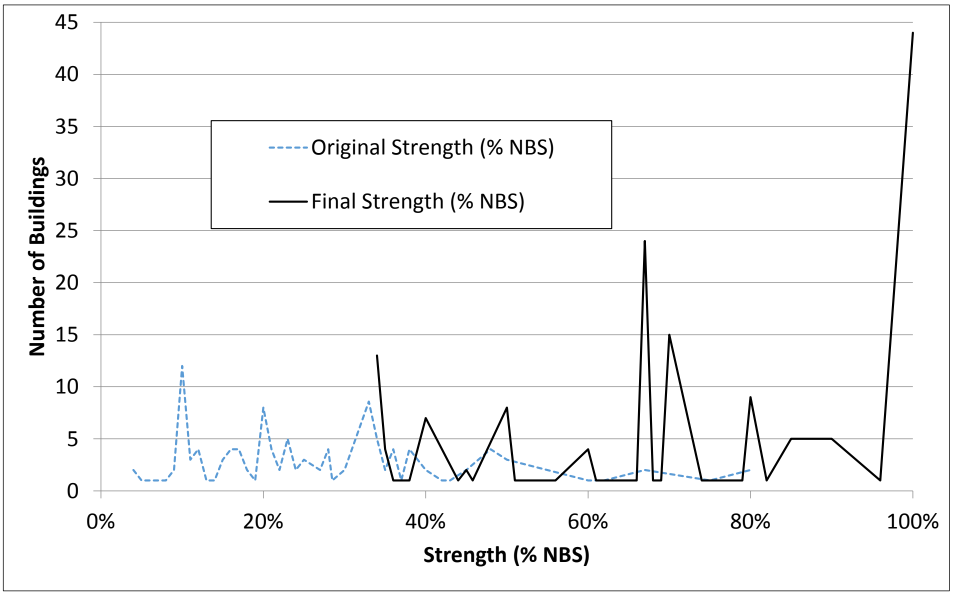

Figure 5. Building Strength before and after Strenghthening

The dashed line shows the original strength before strengthening and the solid line the final strength after strengthening. For the original strength there are 22 unknowns and two unknowns for the new strength. The average strength has increased from 28% with a standard deviation of 15% to 72% with a standard deviation of 22%. The most common value for original strength was 33%NBS and the most common final value is 100% NBS, with another significant peak at 67% NBS.

Table 1. Summary of Level of Strength Improvements (Categories from NZSEE 2009).

Original Strength Category	Strength Category Range (% NBS)	Final Strength Category			
		C	B	A	Total
D or E	33 or less	43	31	29	**103**
C	34-66	2	6	23	**31**
B	67-79	-	-	3	**3**
A	80-100	-	-	2	**2**
Unknown		3	8	9	**20**
Total		**48**	**45**	**66**	**159**

Only a small proportion of the buildings have been strengthened to 34%. Some of the others may have overshot the 34% minimum because of the difficulty of designing a strengthening scheme to an exact level, or because the cost of going to a slightly higher level is insignificant, but obviously many building owners have deliberately aimed to achieve at least 67%, or 100%, with over two thirds of the buildings (70%), achieving at least 67% NBS after strengthening.

A very significant result is that 35% of buildings subject to a consent for strengthening were already at a level of strength 34% NBS or more.

Table 2. Floor Area Summary of Level of Strength Improvements (Categories from NZSEE 2009)

Original Strength Category	Strength Category Range (% NBS)	Final Strength Category			
		C (m^2)	B (m^2)	A (m^2)	Total (m^2)
D or E	33 or less	100985	55411	82248	**238644**
C	34-66	2570	27331	91071	**120972**
B	67-79	-	-	1657	**1657**
A	80-100	-	-	29650	**29650**
Unknown		11490	11578	58116	**81184**
Total		**115045**	**94320**	**262742**	**472107**

These results have also been assessed as a function of floor area, as many earthquake prone buildings are very small in size, one in this study with a floor area of only 70 m^2, and just under half the sample with floor areas of less than 1000 m^2. The level of strengthening is more marked when based on floor area, with 76% of total floor area of buildings achieving a level of strength of 67% NBS as shown in Table 2. Floor area for buildings with multiple consents has been only counted once, but buildings that have undergone two steps in strengthening have been counted twice. The most significant building being of about 9000 m^2, which was strengthened from 20 to 40%NBS in 2007, and this was increased to 80%NBS in 2011. It cannot be assumed why this building was strengthened twice, but the most likely reasons are tenant demand, insurance considerations, or changes in the owner's attitude towards strengthening since the Christchurch earthquakes. These figures should be compared with a total building stock floor area in Wellington City of about 14,500,000 m^2 (Martin Jenkins, 2012).

Even more significantly is that 49% of the floor area of buildings undergoing strengthening was in buildings that were not deemed earthquake prone. Taller buildings were also strengthened to a higher level with the average for buildings of ten storeys or more being 87%NBS, but 70%NBS for buildings of less than ten storeys. It can therefore be deduced that larger buildings are more likely to be strengthened when above the "earthquake prone" criteria, and also are strengthened to a higher level. A reasonable assumption is that it is more economically viable to strengthen a larger building and/or the benefits of strengthening in attracting or retaining tenants is more marked.

3.3 **Types of Structure and Strengthening**

The structural type of buildings has been classified using the WCC classification system and summarised in Table 3. The four categories of timber frame buildings have been combined into two, ignoring the distinction between heavy and light roofs. Some buildings have more than one type of structure, and most incorporate strengthening of more than one aspect or type.

Table 2. Structure Types and Strengthening Methods

Structure Type	No. Buildings with this type of structure	Type of Strengthening								
		New Portal/MR frame	Strengthen Column, Beam, Joint[1]	New Shear Wall	Strengthening existing walls	New Bracing[2]	Strengthening diaphragms	Tying diaphragms to walls	Removing walls etc.[3]	Tying non-structural elements[4]
Conc Block Shear Walls	43	10	3	7	14	10	19	3	6	5
Conc Column/Beam	40	5	16	4	6	9	6	2	2	7
Conc Column/Beam w ConcBlock Infill/walls	40	5	9	9	10	12	7	4	7	3
Conc Column/Beam w URM Infill/Walls	5	1	0	0	2	0	1	0	0	2
Insitu Conc Shear Walls	1	0	0	0	0	0	1	0	0	0
Institu Conc Shear Wall w URM Element	3	1	0	1	2	0	0	1	0	1
Steel Frame/Portal w Heavy Cladding/Walls	8	3	1	2	3	3	3	1	0	0
Steel Frame/Portal w Light Cladding	4	1	0	0	0	0	0	0	0	0
Timber Framing	17	2	0	4	3	7	8	1	0	5
Timber Framing w Conc/Block Element	8	5	1	2	3	2	1	1	1	0
Timber Framing w Light Roof And URM Element	4	1	1	0	2	1	2	0	1	0
Unknown	4	1	0	0	0	2	1	0	0	0
Total	**177**	**35**	**31**	**29**	**45**	**46**	**49**	**13**	**17**	**23**

Notes: 1. With additional reinforcing and concrete, carbon fibre etc.
2. K bracing or cross bracing, may also require new beams.
3. Removing walls and/or other elements to reduce mass and/or stiffness
4. Such as chimneys, parapets, stairs, partitions etc.

Most of the buildings in the data are concrete with roughly the same proportions of block shear walls; frames and concrete block in-filled frames. There are a few concrete frames with masonry infill. Few steel frame buildings are in the sample and about 14% are timber framed. Few have been classified as unreinforced masonry. The most common approach to concrete frame buildings is to strengthen the existing frame whereas with buildings with shear walls, adding bracing or strengthening existing walls is the most common approach. Strengthening diaphragms is common in all building types, but removing walls and other elements is most common in concrete shear wall structures. For timber frame structures the most common approach is to add bracing and strengthen the diaphragms.

The lack of buildings in the unreinforced masonry category is surprising, but there are several possible reasons for this:-

- They have been strengthened or demolished previously under earlier WCC policies
- They are smaller and of lower value so strengthening is uneconomic
- Tenants are smaller businesses and organisations that don't have the intent or ability to influence the standard of buildings they occupy
- Heritage issues complicate the design and cost of strengthening schemes meaning they take longer for decisions to be made and strengthening schemes to be developed.

4 FUTURE TRENDS

The demand for improved seismic performance of buildings is likely to continue in the short term, but is likely to drop off as memory of the Christchurch earthquakes fade. Future earthquakes may occur in New Zealand and affect this outcome. Requirements of insurers are less likely to reduce, and will be affected by earthquakes elsewhere. The proposed policy from the Ministry of Building, Innovation and Employment (MBIE, 2012), that was recently out for consultation, will if enacted, directly increase the rate of strengthening of buildings, and also provide an impetus for buildings to be strengthened even more rapidly as tenants will have more information on the seismic performance of the buildings they occupy and as a consequence demand higher levels of seismic performance.

5 CONCLUSIONS

The number of consents applied for from Wellington City Council has dramatically increased between 2007 and 2012, and the floor area of buildings these consents cover even more so. The average level to which buildings have been strengthening to has also doubled in that time frame. Most buildings are now strengthened to reasonably high levels, with 70% by consent number and 76% by floor area strengthened to at least 67%NBS. Larger and taller buildings are being strengthened to a higher level, probably because the costs are lower in proportion to the building value, and higher benefits with reduced insurance premiums and commanding higher rentals from tenants who are now more aware of earthquake risks. Methods of strengthening appear to be closer related to the structural type of the building, but there are surprisingly few unreinforced masonry buildings in the dataset.

Although reasons for building strengthening cannot be readily assumed, there is a dramatic increase in the number of buildings being strengthened, total floor undergoing strengthening, and the levels to which buildings are being strengthened too. The timing of these changes strongly indicate these are direct and indirect consequences of the Christchurch earthquakes which have raised the awareness of earthquake performance of buildings leading to tenant and insurer demand to strengthen buildings.

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ACKNOWLEDGMENTS:

The Authors would like to thank Wellington City Council and Victoria, University of Wellington for funding this project.