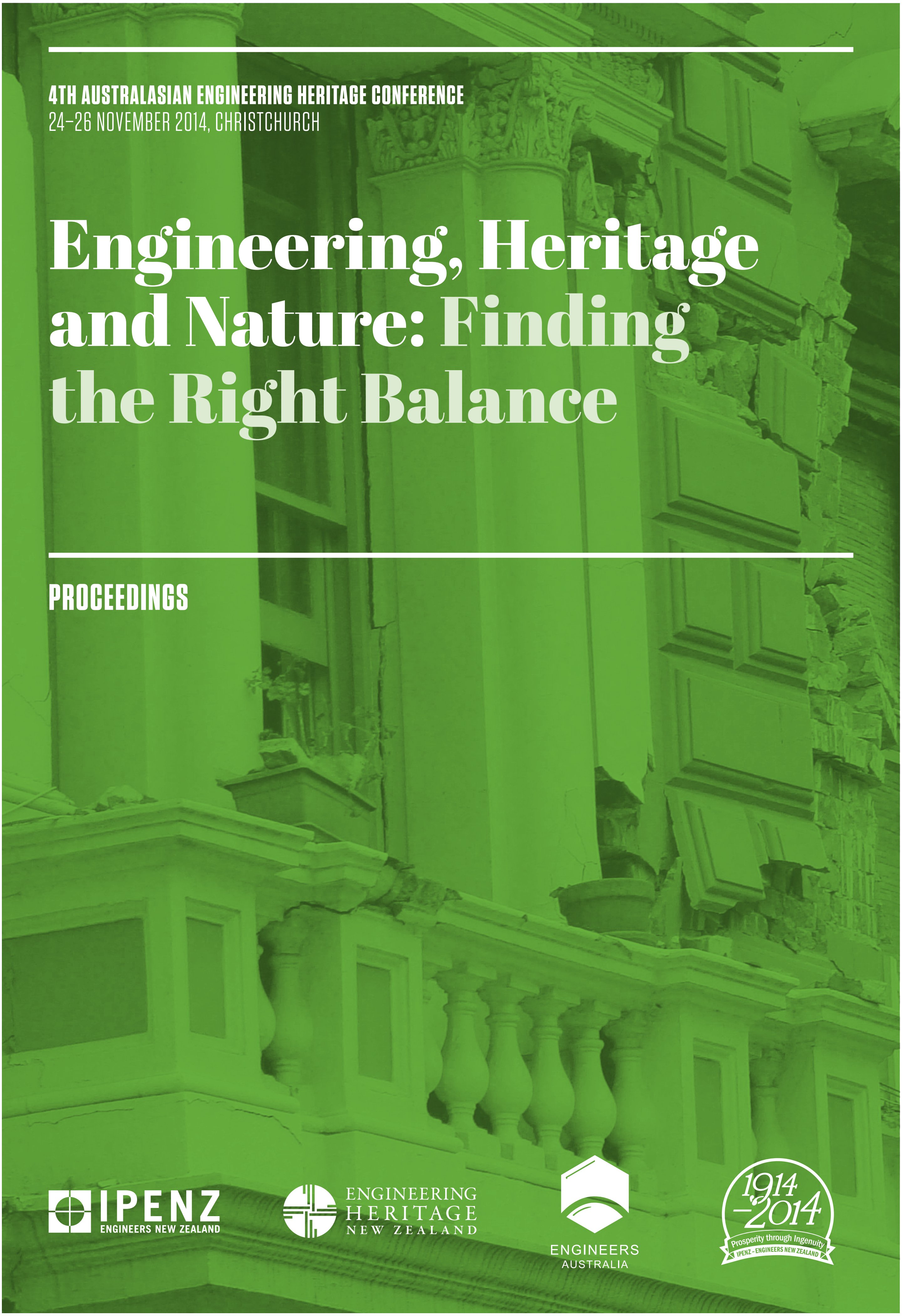

4TH AUSTRALASIAN ENGINEERING HERITAGE CONFERENCE
24–26 NOVEMBER 2014, CHRISTCHURCH

Engineering, Heritage and Nature: Finding the Right Balance

PROCEEDINGS

IPENZ ENGINEERS NEW ZEALAND
ENGINEERING HERITAGE NEW ZEALAND
ENGINEERS AUSTRALIA
1914–2014 Prosperity through Ingenuity IPENZ – ENGINEERS NEW ZEALAND

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Introduction

The Conference Organising Committee, the Institution of Professional Engineers New Zealand (IPENZ), its Engineering Heritage Board and Engineers Australia, are pleased to present the 4th Australasian Engineering Heritage Conference at Lincoln University, Canterbury, New Zealand, 24–26 November 2014.

The first Australasian Engineering Heritage Conference, in 1994, was held in Christchurch and the return to Canterbury of this year’s conference is timely. The conference theme, “Engineering, Heritage and Nature: Finding the Right Balance,” and the event's location, make this conference especially topical and relevant with the region being three years into its post-earthquake recovery process.

The conference has special significance because it is one of the culminating events of IPENZ’s centenary year. The Institution, founded as the New Zealand Society of Civil Engineers in 1914, has been celebrating its history with an exciting programme of events and activities held around the country to commemorate this significant milestone. As well as looking back, the Institution is using the centenary to look to the future as IPENZ positions itself to respond to the challenges of the next 100 years. Many of the conference papers express similar ideas by discussing past and present engineering approaches to natural risks and challenges with the aim of promoting longevity of heritage structures and developing the mechanisms to do this.

The contribution of the paper authors and presenters is gratefully acknowledged. We especially thank our keynote and guest speakers, John Trowsdale and Paul Mahoney, for accepting the invitation, and generously giving their time, to open each day of the conference. The success of the conference is also possible because of the generous support of our joint Platinum Sponsors: Holmes Consulting Group and Fletcher Construction Limited.

The conference features a pre-conference tour exploring the engineering heritage of the upper South Island, partners’ programmes and post-conference tours. The Christchurch-based Conference Organising Committee deserves recognition for its voluntary work in bringing the conference to life at a time when committee members are still rebuilding their lives after the severe earthquakes of 2010 and 2011. The support from IPENZ National Office staff is greatly appreciated too.

Finally, on behalf of the IPENZ Engineering Heritage Board I would like to wish all conference delegates an interesting, inspiring and successful conference.

Robin Dunlop, IPENZ Engineering Heritage Board Chairperson
November 2014

Table of Contents

Introduction i

Keynote speaker 1

Paper author biographies 1

Conference Papers
Note: papers are listed alphabetically by the first author's surname.

Karen Astwood, *Learning from experience: Three case studies of New Zealand natural disasters and engineers' responses, 1878–1953* 7

William M Baker, Nicholas D Molcsan and Andrew H Buchanan, *Callender-Hamilton Truss Bridges: The New Zealand History* 16

John Brown, Kevin Walsh and Patrick Cummuskey,
The four R's – Reduce Risk, Raise Resilience: Local authority priorities and the Auckland perspective on engineering requirements for heritage buildings 24

William Cottrell, *Research Before Restoration* 38

John Duder and Dave Veart, *Engineering Heritage and Nature, Finding a Balance: An Auckland Perspective on the Effects of Natural Hazards on Coastal and Marine Heritage* 45

Helen Ferner Aaron Beer and Mark Spencer, *Heritage Buildings - Seismic Risk Management, A Structural Engineer's Perspective* 51

Simon Fleisher, *Wellington Cable Car and its Engineering Heritage* 60

Mark Hedley, *The Strengthening of Heritage Buildings – Construction Challenges* 68

Mark Hedley and Dean Bennett, *The Strengthening of Heritage Bridges – Construction Challenges* 74

Roger Hodgkinson and Murray John Service, *Tuapeka Mouth Ferry: Taking heritage into the future* 81

Nigel Isaacs, *Hiding in Wellington – New Zealand's First Hollow Concrete Block Buildings* 89

Glen Koorey, *Learning from Failures: Using Historical Engineering Projects to Teach Better Professional Engineering Skills* 96

Paul Mahoney and Colin Zeff, *Sawmill Engineering in New Zealand* 102

Paul Mahoney and Kate Zwartz, *An Inglis Portable Bridge Survivor* 108

Ken McInnes and Lenore Frost, *Three New Zealand Engineers in Colonial Victoria - Brees, Holmes, and Richardson* 113

A L R (Rob) Merrifield, *An Exercise in Large Scale Joinery: Restoration of Three Historic Wellington & Manawatu Railway Carriages* 135

Barbara Rouse and Helen McCracken, *Improving the risk management of New Zealand's historic heritage and the role of the heritage engineering community* 141

Bevan White, Geoff Anderson and Jerry Kearney, Seismic Strengthening and Restoration of Cargill's Monument 151

Author biographies

KEYNOTE SPEAKER

John Trowsdale is Holmes Consulting Group's Project Director, heading up a team providing the on-site dedicated resource for the seismic strengthening and restoration of the Arts Centre of Christchurch. The former Canterbury College campus, known as the Arts Centre, covers a city block and includes 22 heritage buildings, including New Zealand's first university School of Engineering. The Arts Centre suffered significant damage as a result of the destructive earthquake activity of 2010–2011. Due to be completed in 2019, this intricate and extensive, $290 million, project is currently one of the world's largest heritage restoration and strengthening programmes.

John has over 25 years' experience in the construction industry, including 10 years of specialist structural design experience and seven years as Holmes Consulting Group Queenstown office's Business Manager. The day of the 22 February 2011 earthquake, John was engaged to provide engineering support to the Urban Search and Rescue (USAR) team. Following his work with USAR, John immediately started on the Arts Centre site, assessing, shoring, and stabilising structures. Now 3.5 years on and acting as structural engineer, lead consultant and engineer to the contract, John leads a team of seven site-based Holmes Consulting Group staff, and further engineering and drafting resource based in the Auckland and Queenstown offices. His role also extends to co-ordinating site staff and contractors, and liaising with Christchurch City Council and Heritage New Zealand.

PAPER AUTHOR BIOGRAPHIES

The paper author biographies are presented in alphabetical order by surname.

Geoff Anderson is a structural engineer who graduated from the University of Canterbury with a Bachelor of Engineering (Civil)(Hons) in 2008. He has since worked as a structural design engineer for Spiire NZ, based out of Dunedin.

He has an interest in historic structures having undertaken seismic assessments on a number of unreinforced masonry buildings in Dunedin, as well as working on refurbishment and strengthening projects involving places on the New Zealand Heritage List/Rārangi Kōrero, such as Cargill's Monument, Dunedin (2010), the St David Street pedestrian bridge (2011 and 2014) and Dog Island Lighthouse near Bluff (2011–2013).

Paper (with Jerry Kearney and Bevan White): *Seismic Strengthening and Restoration of Cargill's Monument.*

Karen Astwood graduated with a Master of Museum and Heritage Studies from Victoria University of Wellington in 2008, then worked as a contract historian primarily for Heritage New Zealand. Since 2010 she has been the Institution of Professional Engineers New Zealand's part-time Heritage Advisor. In this role she has researched and written many engineering heritage assessments and related material, and in 2014 represented IPENZ in the television documentary series *Making New Zealand*. Karen is currently the Professional Historians' Association of New Zealand/Aotearoa's Secretary.

Paper: *Learning from experience: Three case studies of New Zealand natural disasters and engineers' responses, 1878–1953.*

William Baker graduated from the University of Canterbury in 2013 with a Bachelor of Engineering (Civil), and is currently completing his Bachelor of Commerce (Finance and Economics) at the University of Auckland. When he is not unpacking archive boxes, he enjoys competing in triathlons, travelling, skiing and tramping with his friends. He recently represented New Zealand in Europe competing at the Cross Triathlon World Championships. He hopes to relocate to relocate to Sydney upon completing his degree to work in the financial sector.

Paper (with Nick Molscan and Andy Buchanan): *Callender-Hamilton Truss Bridges: The New Zealand History.*

Aaron Beer is a Beca Technical Director – Structural Engineering, with a passion for seismic design and historic buildings.

His design experience is quite varied ranging from the Sky Jump on Auckland's Sky Tower to the Sky City Conference Centre and developments at Auckland Airport. He has also designed seismic strengthening for many buildings, some historically significant, for example Shed 10 on Auckland's waterfront and currently Alfred Nathan House at the University of Auckland.

Aaron is sought out to provide pragmatic advice on addressing complex seismic issues associated with existing buildings from churches and kindergartens to industrial buildings.

Paper (with Helen Ferner and Mark Spencer): *Heritage Buildings - Seismic Risk Management: A Structural Engineer's Perspective.*

Dean Bennett obtained his Civil Engineering Masters Degree in the United Kingdom prior to working on a number of railway structure projects in London. He moved to New Zealand 18 months ago where he began employment with Downer NZ Ltd. as a Site Engineer working on an array of projects that include Colombo Street Bridge in Christchurch. In his spare time he enjoys cycling, hiking, skiing and playing racquet sports.

Paper (with Mark Hedley): *The Strengthening of Heritage Bridges – Construction Challenges.*

John Brown has over twenty years' experience as a heritage specialist, with a background in archaeology, historic building recording and materials analysis, museums and community engagement, environmental planning and consulting. John leads the Built Heritage Implementation team at Auckland Council – a very strong team of heritage specialists and conservation architects. Their focus is on the delivery of Council heritage policies, provision of advice to Auckland Council organisations, commercial organisations, stakeholder groups and the general public.

Paper (with Kevin Walsh and Patrick Cummuskey): *The four R's – Reduce Risk, Raise Resilience: local authority priorities and the Auckland perspective on engineering requirements for heritage buildings.*

Dr Andy Buchanan is Professor Emeritus of Structural Engineering at the University of Canterbury. He has a B.E. (Honours) from University of Canterbury (1970), a Masters from University of California (1972), and a Ph.D. from University of British Columbia (1984). Prior to joining the University of Canterbury in 1987, he was a consulting structural engineer in Christchurch. He is a Chartered Professional Engineer and a Distinguished Fellow of IPENZ, with special interests in timber engineering, fire safety, earthquake engineering, and sustainability. He is the author of *Structural Design for Fire Safety* and the *NZ Timber Design Guide*.

Paper (with William Baker and Nick Molscan): *Callender-Hamilton Truss Bridges: The New Zealand History.*

William Cottrell is the son of a Canterbury farmer, has worked in Radio New Zealand and then TVNZ as a film editor, followed by experience at London ITN as a video editor. Shifting focus, in London he trained in antique restoration. Upon return to New Zealand he continued his restoration work based in Newmarket, Auckland. He built up a large New Zealand colonial furniture collection, much of which is now in museums with most [50 items] in Museum of New Zealand Te Papa Tongarewa, and some on loan to Government House. He restored the historic *Gunyah* homestead in Glenroy, opening it to the public, but the house was sadly wrecked in the 2010 earthquake. He is the author of *Furniture of the New Zealand Colonial Era* which received two national awards in 2007. William is now at the University of Canterbury completing his PhD on the travel of designs across the 19th century world and is currently researching the traditional use of timber in colonial New Zealand.

Paper: *Research Before Restoration.*

Patrick Cummuskey is a Kiwi and, while he has travelled extensively, has lived his whole life here in New Zealand. Patrick has worked for Auckland City and Auckland Council for a total of seven years, most of that on seismic hazard issues within the Building Control Department. He is a graduate of the University of Auckland in Psychology and Geology, and holds professional memberships with IPENZ, the New Zealand Society for Earthquake Engineering and New Zealand Geotechnical Society. Outside of work Patrick is a qualified ambulance officer and volunteers for St John Ambulance.

Paper (with John Brown and Kevin Walsh): *The four R's – Reduce Risk, Raise Resilience: local authority priorities and the Auckland perspective on engineering requirements for heritage buildings.*

John Duder BE FIPENZ JP is a consulting civil engineer with 50 years' experience in water resource and coastal engineering projects. He was a founding member of the New Zealand Coastal Society and is a member of IPENZ's Auckland Engineering Heritage Chapter. He has worked in Nigeria, Pakistan, South East Asia and around the South Pacific, firstly with United Kingdom consultants and then for 30 years with Tonkin & Taylor Ltd. out of Auckland. As an independent consultant he is happily settled back in Devonport, specialising in smaller dams, surrounded by volcanic cones and trusting that Rangitoto, just across the harbour, has fulfilled its destiny.

Paper (with David Veart): *Engineering Heritage and Nature, Finding a Balance: An Auckland Perspective on the Effects of Natural Hazards on Coastal and Marine Heritage.*

Helen Ferner is a Beca Technical Director - Structural Engineering. She was based in San Francisco during the Loma Prieta and Northridge earthquakes where she gained extensive seismic engineering skills in the assessment and strengthening of existing buildings. This included the seismic strengthening of the 1903 Hearst Memorial Mining Building at the University of California, Berkeley and the 1902 Green Library, Oakland both listed heritage buildings.

Helen has more recently applied these skills here in New Zealand where she was responsible for leading the Beca response to our clients following the recent Christchurch earthquakes and is currently leading the Beca technical development for the assessment and strengthening of existing buildings and is providing advice to a wide range of clients on seismic matters including King's College, Auckland District Health Board, St Cuthbert's College, Sanitarium and Auckland University amongst many others.

Paper (with Aaron Beer and Mark Spencer, *Heritage Buildings - Seismic Risk Management: A Structural Engineer's Perspective.*

Simon Fleisher is a Chartered Engineer and graduated with a Master's Degree in Mechanical Engineering from Bristol University. He served 16 years in the Royal Navy and then 4 years in the Royal New Zealand Navy as a Marine Engineering Officer after immigrating to New Zealand in February 2008. He previously worked for Energy for Industry and Meridian Energy on a variety of electricity generation projects before joining WCCL as the CEO in October 2013. He was elected a Fellow of the Institution of Mechanical Engineers in 2011 and he also serves on the national executive committee of the IPENZ Mechanical Engineering Group.

Paper: *Wellington Cable Car and its Engineering Heritage.*

Lenore Frost BA (Latrobe), GDipLib&InfSc (MCAE), FRHSV, is a Councillor of the Royal Historical Society of Victoria, a past Vice-President, and was appointed a Fellow of the RHSV in 2014. She was also a long-term member of the Essendon Historical Society, serving in various positions there, including President, and was made a Life Member in 2012. Lenore is a community historian who has published a number of books on local and family history topics, including *Dating Family Photos, 1850-1920* and *Fine Homes of Essendon and Flemington, 1846-1880.* In paid employment Lenore worked for the Australian Bureau of Statistics.

Paper (with Ken McInnes): *Three New Zealand Engineers in Colonial Victoria - Brees, Holmes, and Richardson.*

Mark Hedley is a Senior Engineer for Downer NZ Ltd. and is currently working on the Christchurch Earthquake Rebuild. He has designed temporary works for the last 15 years and has an involvement with Downer's graduate programme.

Papers: *The Strengthening of Heritage Buildings – Construction Challenges* and (with Dean Bennett) *The Strengthening of Heritage Bridges – Construction Challenges.*

Roger Hodgkinson was raised at Tuapeka Mouth in South Otago and sheep farmed three kilometres north of the Tuapeka Mouth Punt site. He is a strong advocate for the punts retention and publicising the importance of the punt as a valuable New Zealand heritage item. He recently applied to Heritage New Zealand to have the Punt site acknowledged as a heritage item and it was subsequently recognised on the New Zealand Heritage List/Rārangi Kōrero as a Category 1 historic place. Roger founded the Clutha Valley Tuapeka Heritage Trust and one of their central activities is the retention and promotion of the Punt. Roger has recently moved to live in Te Anau.

Paper (with Murray John Service): *Tuapeka Mouth Ferry: Taking heritage into the future.*

Nigel Isaacs is a Senior Lecturer, School of Architecture, Victoria University of Wellington. Most of his career has been researching building energy use and end-uses in residential and non-residential buildings. For the past decade he has explored the history of New Zealand building technology, including the teaching of a specialist course, publishing numerous articles (with 46 in *BUILD* magazine www.buildmagazine.org.nz) and several series of National Radio talks. He is about to complete his PhD on the development of the technology of the New Zealand house.

Paper: *Hollow Concrete Blocks 1904-1910.*

Jerry Kearney graduated in 1995 with a Bachelor of Civil and Structural Engineering from the University of Surrey (United Kingdom). Jerry is a Chartered Professional Engineer with 19 years of experience in the construction industry working as both a consultant and contractor in the United Kingdom and later specialising in structural design engineering in New Zealand. Through his design work in the United Kingdom and New Zealand Jerry has gained extensive experience in the areas of repairing and strengthening unreinforced masonry and stone structures.

Paper (with Geoff Anderson and Bevan White): *Seismic Strengthening and Restoration of Cargill's Monument.*

Glen Koorey is a Senior Lecturer in Transportation Engineering at the University of Canterbury, Christchurch, where he teaches traffic engineering and transportation planning as well as design and professional engineering skills. Prior to joining Canterbury in 2004, he worked for 10 years as a consulting engineer and researcher with Opus International Consultants. Glen's wide-ranging technical experience includes considerable work in road safety, speed management, sustainable transport, and highway design/operations. He also has a particular interest in engineering history (especially in New Zealand) and its impacts on present-day society and professional engineers.

Paper: *Learning from Failures: Using Historical Engineering Projects to Teach Better Professional Engineering Skills.*

Paul Mahoney trained as a civil engineer and has worked professionally in heritage since 1981. He also continues a volunteer involvement that started in 1967. He has presented conference papers internationally on a range of engineering heritage topics including: roads, horse tracks, bush tramways, railway infrastructure, bridges and the timber industry. Paul is Heritage Technical Advisor in the Head Office of the Department of Conservation.

Papers: Guest speaker, *Industrial Heritage Preservation – How it unfolded in New Zealand, 1922–1960*; (with Colin Zeff) *Sawmill Engineering in New Zealand*; and (with Kate Zwartz) *The Inglis Portable Bridge.*

Helen McCracken studied at Victoria University and the University of Auckland, and graduated from the latter with MA (Hons) in Anthropology in 1994. She worked a freelance historian in Wellington until 2001, when she began work for Heritage New Zealand Pouhere Taonga, first in the Central Region as a researcher, and later as Registrar in National Office. In 2010 she joined the Ministry for Culture and Heritage, where she is currently a Senior Policy Adviser. Over the last four years she has developed a particular interest in disasters and their impact on heritage, and has completed the International Training Course on Disaster Risk Management of Cultural Heritage, Ritsumeikan University, Kyoto, Japan.

Paper (with Barbara Rouse): *Improving the risk management of New Zealand's built heritage and the role of the heritage engineering community.*

Ken McInnes is an adjunct Teaching Fellow, Swinburne University of Technology and lecturers in Internet and Web Technologies. He has experience as a consulting civil and environmental engineer, in town planning and computer science. Ken has been researching engineering history for four decades, and has served on many statutory, professional and community organisations including: Heritage Council Victoria, Engineering Heritage Victoria (past chair), Engineering Heritage Australia (past chair), and is a former chair National Trust Timber Bridges Committee. He has also helped steer many heritage studies including: City of Melbourne; Docklands; National Trust Concrete Bridges, Metal Bridges, and Masonry Bridges. Ken's other interests include family history, bushwalking, ski-touring, the environment and conservation.

Paper (with Lenore Frost): *Three New Zealand Engineers in Colonial Victoria - Brees, Holmes, and Richardson.*

A L R (Rob.) Merrifield has been a member of IPENZ's Wellington Engineering Heritage Chapter since approximately 2006. He has always had a strong interest in the historic development of transportation and has been a member of the New Zealand Railway & Locomotive Society since 1956, being responsible for its publishing programme for over 20 years and was President, 1995–2006. In 1996 the first of the carriages described in the conference paper transferred from Branch ownership to the central Society and the project described came about. Rob has supported, encouraged, and latterly, worked on this project from its inception.

Paper: *An Exercise in Large Scale Joinery: Restoration of Three Historic Wellington & Manawatu Railway Carriages.*

Nick Molcsan has recently taken a graduate position as a Civil Engineer on Auckland's North Shore after completing his Bachelor of Engineering (Civil) at the University of Canterbury. He is currently working in a site management role on a range of projects, with a land development and infrastructure focus. Contributing to his busy life up in Auckland are his representative hockey commitments, avid interest in music and a perpetual thirst for exploring the outdoors. Despite all this, he can always find time to catch up with friends over a drink to plan the next intrepid adventure.

Paper (with William Baker and Andy Buchanan): *Callender-Hamilton Truss Bridges: The New Zealand History.*

Barbara Rouse has a background in environmental science and resource management, with roles ranging from hands-on paint chemist and regional council compliance work to environmental policy advice and project managing the development of New Zealand standards. Central government roles include reviewing the environmental impacts of major mining projects and preparing regulations for energy efficiency and electricity transmission. Recently she retrained in history, specialising in medieval environmental management, before turning to the task of advocating for protecting New Zealand's heritage. Barbara is currently the Senior Heritage Policy Advisor with Heritage New Zealand Pouhere Taonga.

Paper (with Helen McCracken): *Improving the risk management of New Zealand's built heritage and the role of the heritage engineering community.*

Murray John Service (John) graduated from the University of Canterbury and Melbourne University in 1968 and 1972 with a BEmech and MEngSci. Subsequently he worked for Air New Zealand, and then went to Japan as an English teacher at Fukui Institute of Technology. During his seven years in Japan, he worked on developing a linear turbine. He presented two papers on linear turbines at ASME conferences in the United States of America, and demonstrated the feasibility in Thailand. John is a Patent Attorney, and a member of Engineers Without Borders Auckland, where he is promoting the linear turbine concept for developing countries.

Paper (with Roger Hodgkinson): *Tuapeka Mouth Ferry: Taking heritage into the future.*

Mark Spencer is General Manager Buildings at Beca and a Technical Director - Structural Engineering. He has led the design of numerous very large scale and complex projects in New Zealand and across South East Asia and the South Pacific including the US$250 million Macau Tower and Entertainment Centre and the 450,000m2 Pacific Place mixed use development in central Jakarta.

Following the recent Christchurch earthquakes Mark has been heavily involved in providing advice on seismic risk management to a wide variety of clients and organisations including for example ASB, AUT University, Brookfield, Westpac and IAG insurers, amongst many others.

Paper (with Helen Ferner and Aaron Beer): *Heritage Buildings - Seismic Risk Management: A Structural Engineer's Perspective.*

David Veart LLB, MA (hons), trained originally as a lawyer and later went on to teach in New Zealand and the United Kingdom. In 1981 he retrained as an archaeologist and worked in that capacity until 2013 for both the New Zealand Historic Places Trust and the Department of Conservation. He now works as a full time writer and is the author of three books including, Digging Up the Past: Archaeology for the Young and Curious.

He is a member of the Auckland Council Heritage Advisory Panel, chairman of the Devonport Peninsular Trust, a Trustee of the Frank Sargeson Trust, committee member of the Devonport Museum and Historical Society, a trustee of the Rangitoto Island Historic Conservation Trust and a member of IPENZ's Auckland Engineering Heritage Chapter. He is also a member of the New Zealand Archaeological Association, the New Zealand Society of Authors and the Association of Handcraft Printers.

Paper (with John Duder): *Engineering Heritage and Nature, Finding a Balance: An Auckland Perspective on the Effects of Natural Hazards on Coastal and Marine Heritage.*

Kevin Walsh is a doctoral student at the University of Auckland, supervised by Jason Ingham. He consults regularly on seismic assessments and works part-time at the Auckland Council helping the council evaluate the risks of its building property portfolio. Kevin earned his Masters at the University of Notre Dame in the United States of America, where he is a licenced professional engineer.

Paper (with John Brown and Patrick Cummuskey): *The four R's – Reduce Risk, Raise Resilience: local authority priorities and the Auckland perspective on engineering requirements for heritage buildings.*

Bevan White is Senior Structural and chartered professional engineer for Spiire NZ, currently based in Nelson. Over a 32 year career, practising in both New Zealand and Australia in the fields of structural engineering design and construction, Bevan has gained expertise in seismic design and assessment of commercial and industrial buildings.

Bevan has a special interest in unreinforced masonry and stone structures and notable historic projects include: Cargill's Monument (2009–2011), Stonework repairs to Larnach's tomb in Dunedin (2008), Dog Island Lighthouse near Bluff (2011) and a review of the Akaroa Memorial stone monument earlier this year (2014).

Paper (with Geoff Anderson and Jerry Kearney): *Seismic Strengthening and Restoration of Cargill's Monument.*

Kate Zwartz graduated with a B.E. (Civil)(Hons) from the University of Canterbury, Christchurch, in 1989. Since then, she has worked as an engineer for five years in Africa, and for nineteen years in the Local Government sector. Kate joined the Department of Conservation in 2013, and is now one of five engineers inspecting and managing the bridge assets on Conservation land around the country.

Paper (with Paul Mahoney): *The Inglis Portable Bridge.*

LEARNING FROM EXPERIENCE: THREE CASE STUDIES OF NEW ZEALAND NATURAL DISASTERS AND ENGINEERS' RESPONSES, 1878–1953

Karen Astwood[1]
[1]Heritage Advisor, IPENZ, Wellington, New Zealand; Heritage-Advisor@ipenz.org.nz

Abstract
This paper investigates how significant late 19th- to mid-20th century natural disasters affected the development of New Zealand engineering practice and is the platform for further study on the topic. The purpose of the research is to provide a historical overview of New Zealand's main natural hazards and risks, and the engineering practice developments associated with three selected case study natural disasters: the 1878 Clutha Great Flood, the 1931 Hawke's Bay earthquake and 1953's Tangiwai Disaster. Each case study highlights the role of a notable engineer, expanding the compiled biographical information for Harry Pasley Higginson (1838–1900), Lachlan Bain Campbell (1882–1956) and Charles William Oakey Turner (1901–1994), respectively. Where possible, their first-hand experiences, reactions and responses to the event in which they were involved are included. The case studies show natural disasters have historically been a catalyst for engineering and legislative change in New Zealand as well as increasing public understanding of the profession's role in mitigating risk.

1. Introduction

New Zealand is subjected to a range of natural hazards and risks. Its location on the boundary of the Australian and Pacific tectonic plates has given New Zealand mountainous terrain, volcanic activity and frequent earthquakes. In addition, the country is in the path of the Roaring Forties weather system. As well as being susceptible to extreme wind events, heavy rain systems are driven onto the country, condensing against mountain barriers and triggering flood events. In contrast, many areas are also prone to drought. As an island nation, the tsunami risk is another in a long list of natural hazards.

New Zealand has a history of extraordinary natural events which could be classed as "acts of God". However, New Zealanders appreciate that these are inevitable and, as such, a defining characteristic of the country. This means that alleviating the risk from floods, earthquakes, volcanic activity and other threats has challenged engineers since New Zealand's colonial history began.

Responses from engineers have been collected as part of various oral history and documentary projects undertaken in the aftermath of the 2010 and 2011 Canterbury earthquakes. This prompted the author to consider how engineers have historically been affected by similarly tragic events. This paper is the author's first step towards developing a picture of how significant historic natural events and disasters have tested engineers' problem-solving skills and influenced engineering practice in New Zealand. This paper provides an overview of some of the country's main natural hazards and three case study examples.

The first case study focuses on New Zealand's flood risk, in particular the devastating 1878 Clutha Great Flood in Otago. Over the next few years Dunedin-based consulting engineer, Harry Pasley Higginson (1838–1900), worked extensively in the area, repairing infrastructure damage and advising on engineered flood mitigation measures. The resulting preference for building suspension bridges, generally single span, is a regional engineering heritage legacy of the flood. The event also motivated river control legislation.

Arguably New Zealand's most influential natural disaster was the 1931 Hawke's Bay earthquake. This had a catastrophic effect, especially in the area's most populous town, Napier. The post-quake recovery work was directed by engineers such as Lachlan Bain Campbell (1882–1956), one of Napier's emergency Commissioners. Seismic engineering came to the fore and this event resulted in the development of New Zealand's modern Building Code.

Although not as common as major flooding or earthquake events, volcanic activity has also had calamitous results in New Zealand. The Tangiwai Disaster of 1953 was caused by a lahar originating from the North Island's Mount Ruapehu. It destroyed a railway bridge and subsequently a passenger train ploughed into the swollen Whangaehu River with significant fatalities. Charles William Oakey Turner (1901–1994) was involved in the disaster's Board of Inquiry. The event lead to greater awareness of lahar risk and has resulted in on-going mitigation measures.

The author acknowledges that there are many other events throughout New Zealand's history and engineers who could be profiled in relation to each natural hazard. This paper is an initial stage in building a portfolio of this type of information and an exercise in establishing the format it may take.

2. Flood

New Zealand's storm and heavy rain events have caused significant loss of life and considerable property damage. Shipwrecks with high casualties were a relatively common result of storms, particularly in the 19th and early 20th centuries. Heavy rain has also caused substantial landslides, like the one which caused the Ongarue railway accident (1923), killing 17 people.

However, of the New Zealand's weather-related events, severe floods are the most frequent form of natural disaster and collectively have had the biggest economic impact. [1] Table 1 details some of these events.

Table 1: Examples of notable New Zealand floods, 1840–1950. [2]

Year	Place	Notes
1846	Te Rapa, Lake Taupo	A landslide dam was created by heavy rain which burst killing at least 60 people
1858	Hutt valley	9 people killed
1863	Otago	Approximately 100 killed in flood and snowstorm
1868	Nationwide	Flooding extensive in Canterbury and Otago. 37 people died
1878	Clutha Great Flood, Otago	Extensive and widespread damage. Death toll pf 1–2 people
1908	Manawatu-Whanganui, Wellington, Canterbury and Otago	Widespread stock loses, property and infrastructure damage
1912	Northland, Manawatu-Whanganui, Wellington	Widespread flooding. At least 1 casualty
1923	Upper South Island	Widespread property and infrastructure damage. 3 people died
1936	North Island and Marlborough	High winds and widespread flooding, landslides and washouts. Several casualties.
1936	Canterbury	Extensive damage to infrastructure
1938	Kopuawhara	Flash flood causing 21 deaths
1938	Hawke's Bay, Gisborne	Severe flooding. Esk Valley properties covered in silt and/or destroyed by flood waters and landslides
1944	Northland, Auckland, Waikato, Bay of Plenty and Tasman-Nelson	Widespread stock loses and minor property damage. Many roads were inaccessible.

2.1. Clutha Great Flood (1878)

The Clutha River/Mata-au, known as the Molyneaux River in the early colonial period, has its headwaters at Lake Wanaka and its mouth near Balclutha on the South Island's east coast. Flowing through Otago, it is the country's second longest river at 322 kilometres (km) and has the largest water volume. Its principle tributaries are the Kawarau, Manuherikia, Pomahaka, and Tuapeka Rivers.

The Otago gold rush boosted the population of Central and South Otago in the 1860s and by the 1870s there were many bridges crossing the Clutha River and its tributaries. By this time towns along the river, such as Cromwell, Alexandra, Roxburgh, Beaumont and Balclutha were, or were becoming, well-established. Residents were aware of the area's flood risk because damaging floods had occurred in 1851, 1863 and 1866. [3]

In late September 1878 the region had consistent rain and bouts of heavy rain. It had been a harsh winter and the spring snow thaw pushed river levels even higher. Therefore, the Clutha River and others in the area were in flood for several weeks, inundating large sections of Central and South Otago. The counties underwater included Bruce, Clutha, Tuapeka, Vincent and Lake County. [4]

The Clutha Great Flood is the region's largest recorded flood event. Contemporary reports provide vivid accounts of the devastation. It was noted that:

> For weeks afterwards the extensive plains…continued submerged, only the roofs of houses and tops of trees being visible above the waste of waters. For upwards of fifty miles north and south along the sea coast the shore was strewn with the spoils of the Clutha Valley consisting of bridges, punts, houses, diggers' tents, farming implements, furniture, beds and bedding, carcases of horses, sheep, cattle, pigs, and goats. [5]

The damage to property was considerable and the Public Works Department's (PWD) Engineer-in-Charge for the Middle [South] Island, William Newsham Blair (1841–1891), estimated it would cost the department over £100,000 (NZ$15 million in 2014 currency) to repair or replace government assets in the flood affected region. This information was no doubt collected by the PWD's new Resident Engineer, Edgeworth Richard Ussher (1839–1916), and other staff who inspected the region as the water receded. [6]

County engineers and consultant engineers had a significant post-flood workload too. These included Vincent County's Leslie Duncan Macgeorge

(1854–1939) and Matthew Paterson (1833–1903) for Clutha County. Tasks in the response and recovery phases of the event included: inspecting damage, co-ordinating Council's response, coming up with prioritised repair programmes, lobbying central government for support and designing and project managing the construction of infrastructure such as flood protection works and replacement road bridges. [7]

2.1.1. Harry Pasley Higginson (1838–1900)
In an obituary Higginson was said to be "a gentleman well-known all over New Zealand as an eminent engineer, who took a prominent part in connection with the public works of the colony." [8] His career began with Sir William Fairburn's (1789–1874) prestigious firm in Manchester. Higginson then exported his talents, working in various engineering roles in Russia and India.

Higginson immigrated to New Zealand in 1872, after a brief return to England where he became a Member of the Institution of Civil Engineers (M.Inst.C.E). His first role in the colony was as the South Island's Superintending Engineer for the Railways Department. [9] While in government employ he also had some consulting work and Higginson entered into private practice in mid-1878, based in Dunedin. [10]

Figure 1: Harry Pasley Higginson [*circa* 1876]. Ref: 1/2-066660-F. Alexander Turnbull Library, Wellington, New Zealand. http://natlib.govt.nz/records/23233113.

Professionally this was a timely and shrewd move because within months the Clutha Great Flood occurred and Higginson's services were in high demand. Over the next six months, Higginson was engaged on many reports for various local River Boards and Councils about mitigating future flood risk. [11]

Higginson was also on the 1880 Commission of Enquiry into the significant flood damage around Balclutha, alongside Blair and Charles Napier Bell (1835–1906). In addition to PWD works completed after the event and those being planned, the Commission recommended constructing two storage reservoirs in the Upper Taieri Basin, alterations to existing stopbanks and removal of others, raising railway embankments, and creating floodgates in all culverts. [12] Of course, recommendations are not directives and it seems not much was done about the extra initiatives. [13]

Meanwhile, after focusing on post-flood work for several years, from 1882–1886 Higginson was the Chief Engineer for the Manawatu and Wellington Railway. Higginson retired from his subsequent position as the Engineer and Manager of the Wellington Gasworks in 1898. [14]

2.1.2. Engineering practice legacy
All but four of the road bridges between Balclutha and the Central Otago lakes were destroyed by the Great Flood, so designing bridges likely to withstand future floods became an important consideration. [15] Higginson and others recommended raising the height of replacement bridges and that scour protection be standard for bridges with piers. Higginson put this into practice with his replacement road bridge at Balclutha (1880–81). [16]

During this period, Higginson also designed the Kawarau Gorge Suspension Bridge, which was one of many local road suspension bridges constructed in the aftermath of the Great Flood. Because of the fast flowing rivers, there were many suspension bridges in the region prior to the flood. However, some multiple span truss and arch bridges, like that at Roxburgh, were also replaced with suspension bridges because limiting mid-river piers was seen as a relatively inexpensive way of mitigating flood caused failure. [17] A large proportion of these late 1870s and 1880s Central Otago suspension bridges remain. They characterise the region, are an enduring engineering heritage legacy of the Clutha Great Flood and indicate that the post-flood approach to bridge building was valid.

On a national level, the Clutha Great Flood would have been a motivating factor in creating the *River Boards Act 1884*. Similar to the *Roads Boards Act 1882*, the *River Boards Act* repealed 20 individual acts relating to different areas around New Zealand and provided rates taking and other powers to the Boards specifically for the purposes of river maintenance and flood protection. [18]

Many Boards had their own specialist engineer or at least engaged project consultants. However, the legislation was not entirely successful because of the piecemeal approach the river districts created. It was only after the 1938 Esk Valley flood in Hawke's Bay that legislation was passed which placed entire river systems in the control of catchment boards. [19]

3. Earthquake

The risk to life from flooding was particularly significant in mid- to late- 19th century New Zealand. However, in the early 20th century earthquakes claimed this dubious honour mostly due to the 1931 Hawke's Bay earthquake. On average New Zealand has one 4–4.9 magnitude earthquake per day and a 7–7.9 magnitude event every two and a half years. Earthquakes cluster along fault lines but are felt all over New Zealand. [20] Table 2 highlights some significant, large earthquakes dating from the beginning of New Zealand's colonisation until the mid-20th century.

Table 2: Examples of notable New Zealand earthquakes, 1840–1950. [21]

Year	Place	Notes
1843	Whanganui	Estimated magnitude 7.5. 2 people died
1848	Marlborough	Magnitude 7.5. The largest aftershock was magnitude 6.1 and 3 people died
1855	Wairarapa	Magnitude 8.2. Widespread property damage in central Wellington. 7 people died.
1863	Hawke's Bay	Magnitude 7.5
1868	Cape Farewell	Magnitude 7.5
1888	North Canterbury	Magnitude 7.3
1893	Nelson	Magnitude 6.9
1901	Cheviot	Magnitude 6.9. 1 death
1914	East Cape	Magnitude 6.8. 1 death
1929	Arthur's Pass	Magnitude 7.1
1929	Murchison	Magnitude 7.8. 17 people died
1931	Hawke's Bay	Magnitude 7.8. 256 people died. The largest aftershock was magnitude 7.2
1934	Pahiatua	Magnitude 7.6. 1 death
1942	Wairarapa	Magnitude 7.2. The largest aftershock was magnitude 7.0. 1 death. Widespread damage in Wellington

3.1. Hawke's Bay earthquake (1931)

Earnest European settlement of Hawke's Bay, in the North Island's east, began in the early 1850s with runholders occupying large tracts of land for sheep farming. This was followed by the Government establishing towns around the region. By 1931 the population in Hawke's Bay's main city, Napier, was over 16,000.

A magnitude 7.8 earthquake struck the morning of 3 February and a fire subsequently added to the destruction in central Napier. While building collapse was a significant contributor to the death toll, water supply failure also resulted in an uncontrolled fire sweeping through the business district. [22] In Napier 161 people died as a result and the province's death toll was 256, making the event New Zealand's deadliest natural disaster on record. [23]

Engineers offered assistance from around New Zealand in the immediate aftermath. For example, the Engineer-in-Chief, Frederick Furkert (1876–1949), and others from PWD head office arrived in Hawke's Bay within days to start directing vital road repairs, the programme of demolishing and clearing buildings and mobilising a labour force of over 500 people to carry it out. [24]

The earthquake pushed up land, in some places by one to two metres, causing significant damage to water and waste water infrastructure and also the electricity supply to pumps. Within weeks, Wanganui City Engineer, John Stanley Longton Deem (1895–1933) was on hand to oversee the works and Wellington City Council's Engineer, George Hart (1870?–1948), designed a new sewerage system for Napier South by the end of March. [25]

3.1.1. Lachlan Bain Campbell (1882–1956)

Campbell was a PWD Inspecting Engineer flown to Hawke's Bay within hours of the earthquake and, along with magistrate John Saxon Barton (1875–1961), was soon appointed one of Napier's earthquake recovery Commissioners. [26]

Born in Waiapu, Campbell studied at Canterbury College before becoming a Public Works Department engineering cadet in 1901. His early focus on the North Island Main Trunk's (NIMT) construction lead to similar work around the North Island. He was a foundation member of the New Zealand Society of Civil Engineers in 1914 (he was the Auckland Branch President in 1927) and was also M.Inst.C.E. During World War One, Campbell was awarded the Military Cross. [27]

Immediately prior to the war, Campbell had been Napier's PWD Resident Engineer. After his war service Campbell travelled and then came back to New Zealand to continue progressing through the PWD's ranks. He soon became District Engineer in Dunedin and then Auckland in 1924. Following the career progression of his predecessor, Alfred James Baker (1881–1943), he was promoted to Inspecting Engineer in late 1928. [28] It was in this capacity he first became involved in Hawke's Bay earthquake response work. Within days he was made the PWD's temporary controlling officer in Hastings, Hawke's Bay's second largest city, in charge of the demolition of dangerous buildings. [29]

The lack of co-ordinated national disaster management was immediately highlighted after the earthquake and legislation was quickly pushed through Parliament to compensate. Passed in April, the *Hawke's Bay Earthquake Act 1931* formed the Hawke's Bay Adjustment Court and Rehabilitation Committee which basically held the Government purse-strings. The Act also ratified Barton and Campbell's appointments as Napier's Commissioners and the emergency powers they had been given by the Municipal Council to effectively manage the city's recovery and reconstruction. [30]

Campbell stated that "what was needed [in Napier] was a broad outlook and not a confusing mass of detail." Indeed, this seems to have been his mandate – to have the overview of infrastructure and other building required and to co-ordinate the city's rebuild as speedily and cost effectively as possible. [31]

Campbell was engaged in Napier for over two years and his work which "Napier in a large measure owes much" was appreciated and praised. [32] Campbell was soon appointed Secretary of the Marine Department, remaining in the position until he retired in 1944. [33]

Figure 2: Foundation members of the New Zealand Society of Civil Engineers, 1954 (detail). From left to right: Hugh Vickerman, Lachlan Bain Campbell and Henry Featherston Toogood. [34] Image courtesy of IPENZ.

3.1.2. Engineering practice legacy

Seismic design was already a focus for the PWD in the wake of the 1929 Murchison earthquake and current best practice was a feature of Napier's Chief Post Office. [35] Completed in 1930, this building was one of only a few central Napier buildings to survive the earthquake, but was gutted by the fire. The PWD had a wide reach and the Hawke's Bay earthquake affirmed the validity of considering seismic resistance in building design. After the event, the PWD developed its own publically available building standards for implementation on all its projects. [36]

Within weeks of the earthquake, a Building Regulations Committee was established. The committee, chaired by Canterbury College School of Engineering's Professor John Ernest Lelliot Cull (1879–1943), was set up to develop guidelines for the rebuild based on evidence from the disaster, which it seems likely Campbell would have been involved in collecting. The majority of the committee were engineers, including senior consultant and council engineers from Auckland, Wellington and Christchurch and PWD Designing Engineer, William Langston Newnham (1888–1974). [37] This recognised the engineering profession's important role and expertise in building design above that of architects. The committee's recommendations became the forerunner of New Zealand's modern building codes, something the committee advocated for, which was first realised in 1936 with the *Model Building By-Law*. [38]

4. Volcanic eruption

Most of New Zealand's modern volcanic activity has been focused in the North Island's Central Plateau. However, other places, including the country's largest city, Auckland, are potentially vulnerable. With the exception of the 1886 Mount Tarawera eruption, much of New Zealand's volcanic activity since European colonisation began has been spectacular but caused little property damage or loss of life. Excluding White Island, the volcanoes in Table 3 are all located in the Central Plateau.

Table 3: Examples of notable New Zealand volcanic activity, 1840–1950. White Island had fairly low level but continuous eruptions during this period, which have only intensified in the last 40 years.

Year	Mountain	Notes
1861	Mount Ruapehu	Eruption and lahar in Whangaehu River
1868	Mount Tongariro	Forms the upper Te Maari crater
1870	Mount Ngāuruhoe	Culmination of 30 years of frequent eruptions. Lava flows
1886	Mount Tarawera	153 people died
1889	Mount Ruapehu	Eruption and lahar
1895	Mount Ruapehu	Eruption and lahar
1896–97	Mount Tongariro	50 millimetres of ash falls locally and spreads as far as Napier
1903	Mount Ruapehu	Eruption and lahar
1914	White Island	11 people killed in debris avalanche
1925	Mount Ruapehu	Eruption and lahar

1945	Mount Ruapehu	A series of explosive eruptions with lava and ash and rock fall. In 1953 a lahar from the undermined Crater Lake caused the Tangiwai Disaster
1948-49	Mount Ngāuruhoe	Small lava flow, 6 km high ash cloud

New Zealand’s volcanic activity causes different threats, from ash clouds, avalanches, lava flows and domes, pyroclastic flows and tsunamis. Lahars are another aspect of volcanic activity – fast flowing volcanic mudflows of ash and rock often generating from a crater lake and/or melting snow and ice. [39] The density and speed of lahars mean they are especially destructive and people caught in them are unlikely to survive. Lahars are also notoriously difficult to channel or control.

4.1. Tangiwai Disaster (1953)

Mount Ruapehu is New Zealand’s largest active volcano as well as an important part of a World Heritage Site and a centre for leisure activities such as skiing and climbing. At 2797 m high this stratovolcano (composite peak volcano) is the North Island’s tallest peak. Crater Lake dominates the summit. The capacity of this lake is approximately 8 million cubic metres of acid water. [40]

There are several rivers with their headwaters on Mount Ruapehu, including the Whangaehu River. The river’s name, meaning large body of muddy or turbid water in Māori, is suggestive of its history of lahars. [41]

Eruption events in 1945–46 emptied Crater Lake and by December 1953 the re-filled lake was considerably higher than its pre-1945 levels because eruption material had raised the sides. The 1940s activity also altered a water outlet cave Ice crevassing through the ash barrier is thought to have undermined the cave, causing its collapse and sending copious amounts of water down the Whangaehu River and taking old volcanic ash, pieces of glacier ice and gorge boulders with it. Some “vibrations” were detected by a nearby seismograph at the Chateau Tongariro hotel preceding the lahar, so experts did not rule out the possibility that volcanic or earthquake activity hastened the cave’s collapse on 24 December.

The resulting lahar destroyed the rail bridge at Tangiwai, between Waiouru and Ohakune. New Zealand Railways speed and operating procedures were all being followed, but unfortunately the timing of the Wellington to Auckland Express Train meant the locomotive and front carriages plunged off of the failed Whangaehu River Bridge despite application of the emergency brake. The Tangiwai Disaster is New Zealand’s worst railway disaster with a death toll of 151. The nearby road bridge was also destroyed but no casualties resulted.

The steel truss bridge with mass concrete abutments and piers was an original NIMT structure, constructed in 1906. There were no construction files to indicate whether the river’s lahar risk was a design consideration, especially in regard to pier foundation depth, because these and other government records were destroyed in the July 1952 Hope Gibbons Building fire, Wellington. [42]

4.1.1. Charles William Oakey Turner (1901–1994)

Turner was Ministry of Works (MoW) Engineer-in-Chief from 1951–1962. Born and educated in Britain, Turner began his career in New Zealand in the PWD’s national Design Office as an Assistant Engineer in 1926. While in this position he was sent to Napier to assist the Commissioners with the 1931 Hawke’s Bay earthquake recovery. After completing study fellowships in the United States of America, Turner became Chief Designing Engineer in 1937 and then Chief Inspecting Engineer. Turner was also the State Hydro Electric Department’s Chief Civil Engineer, 1946–47, before being transferred back to MoW. [43]

Figure 3: Chief executive officers of the State Hydro-electric Department, 1946 (detail). From left to right: AE Davenport, CWO Turner and S Roberts. [44] Image courtesy of IPENZ.

Turner was involved in the inquiry into the Tangiwai Disaster because of his senior position within the MoW. The inquiry indicated a 1925 lahar mystified the Acting District Engineer who could not account for the flooding since there had been no rain for a fortnight. That event caused considerable scouring, especially around pier 4. In 1944 further flood scour was filled with stone, and then in 1946 eight five-ton concrete blocks were positioned at pier 4 as protective works. [45]

When questioned about the apparent insufficient response in 1925, Turner stated: “It is very difficult for me to get myself away from the present situation.” Based on the information available to the 1925 engineer Turner thought he would have acted similarly; repairing damage promptly and making some enquiries about the lack of rainfall, but not being "unduly perturbed about it". [46]

Despite no significant mitigation steps being taken, the 1925 lahar drew PWD/MoW attention to the potential vulnerabilities of the Whangaehu River road and rail bridges. The MoW seems to have been wary of Mount Ruapehu's volcanic activity particularly during and after the mid-1940s eruptions. The Crater Lake's levels were monitored regularly and a senior engineer was sent to the mountain to make measurements and observations in early 1953. Therefore, Turner was able to estimate that on the night of 24 December the lake dropped over 6 m in two and a half hours which is indicative of the force of the lahar. About 340,000 cubic metres of water is thought to have gushed out of the lake. [47]

Turner retired in 1962. During his tenure as Engineer-in-Chief he was in charge of projects such as the Wairekei Geo-thermal power development, as well as the Cook Strait power cable, among many others. In retirement he consulted on projects, including Manapouri Power Station. [48]

4.1.2. Engineering practice legacy

It was noted in the Board of Inquiry Report that lahar was a term more frequently used by geologists than civil engineers. However, as a result of the Tangiwai Disaster there was wider understanding of this type of natural hazard among engineers and the public in general. [49]

Until 1957 a temporary rail bridge was service at Tangiwai. Obviously, lahar risk was considered in the design of replacement Pratt truss bridge with reinforced concrete cylinder piers. The Railways Department also undertook works on other local bridges in the wake of this event, such as the Mangaturuturu Viaduct further north. [50] There have been at least 13 Mount Ruapehu lahar episodes since 1945, so this is an ongoing aspect of state highway and NIMT management in the region. [51]

The Board of Inquiry recommended bridge failure warning devices be installed on all railway bridges crossing rivers and stream from Mount Ruapehu between Waiouru and National Park. Road bridges were not included in this. There does not seem to have been technology available at the time to create an especially reliable warning system. [52]

Half a century later, such a system was possible and the East Ruapehu Lahar Alarm Warning System was installed by the Department of Conservation (DoC) in 2001–02. It consists of a series of sensors and acoustic flow monitors, whose data feeds back to the base at Tokaanu Power Station and is distributed to various stakeholder agencies through pagers, telephone and Internet. Accepting that not all the risk from lahar can be mitigated, the early alarm system is designed to alert agencies such as the local councils, Police, DoC, electricity, rail and road infrastructure agencies, activating their emergency and evacuation procedures. These include the halting of NIMT trains and road traffic in the area. [53]

5. Conclusion

The case studies show that following significant natural disasters, engineers have taken centre stage and public understanding has increased about the specialist role they have in reducing risks from natural hazards. This has been useful in the aftermath of disasters because it gives an informal mandate for public spending on mitigating future risk, even decades later, as with the East Ruapehu Lahar Alarm Warning System. In some cases, natural disasters, such as the Clutha Great Flood and the 1931 Hawke's Bay earthquake, have been the impetus for creating or refining the regulatory framework various engineering fields operate within.

The case studies all highlight senior engineers and there is scope for providing more specifics, especially their personal, not just professional, reactions. An interesting direction for this type of research could also be to identify younger engineers and to trace whether the natural disaster they were involved in was a formative occurrence affecting their career path and specialisation. Likewise, replicating this case study exercise and surveying other significant natural events may provide a better picture of whether we are cumulatively learning from our natural disaster experiences in a lasting and meaningful way or may end up repeating past mistakes.

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CALLENDER-HAMILTON TRUSS BRIDGES: THE NEW ZEALAND HISTORY

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Abstract
The Callender-Hamilton truss bridge was regarded as the most economical bridge of its time. It was patented in 1935 by Archibald Milne Hamilton (1898–1972), who had graduated with a Bachelor of Engineering (Civil) degree from Canterbury College (now the University of Canterbury) in 1924. The bridge design was first developed in 1927 in Iraq, where he directed the construction of a strategic road for their Public Works Department on behalf of the British Empire. The multi-truss multi-tier bridge system that he developed, known as the Callender-Hamilton bridge, allowed faster than normal construction by unskilled technicians due to its prefabricated components. This bridging technique later proved to be extremely effective and was used in the development of military bridging prior to and during World War II. Over 1000 Callender-Hamilton bridges exist worldwide, across 50 countries. There are at least 16 bridges located in New Zealand that have stood the test of time.

1. Introduction

1.1. Background

A University of Canterbury graduate engineer, Archibald Milne Hamilton, was responsible for the revolutionary design of the Callender-Hamilton truss bridge, expanding the boundaries of what is possible with standardised bridging. The bridge design made immense contributions to military bridging in World War II. Figure 1 shows a photograph of the Gates of Haast bridge on State Highway (SH) 6 on the West Coast of the South Island of New Zealand.

Figure 1: Gates of Haast bridge.

1.2. Purpose of this project

A large collection of Hamilton's previous correspondence, documentation and models were donated to the University of Canterbury by his family. It has been over 80 years since the development of the first Callender-Hamilton bridge and they are still in use around the world. There are 16 Callender-Hamilton bridges located in New Zealand, which are all on state highways in the South Island. It is timely to review this civil engineering pioneer and the contributions he made to pre-fabricated truss bridging. The first two authors agreed to make this investigation as their final year Bachelor of Engineering (Hons) project in Civil Engineering at the University of Canterbury. This paper is very similar to their final report [2].

2. Research methods

2.1. Library and interests

The University of Canterbury library database and the internet were searched to find material on Callender-Hamilton bridges, military bridging and Archibald Milne Hamilton. The findings were used to gain a technical understanding of the bridge design, as well as identifying the different kinds of bridges available for military usage prior to World War II.

2.2. University of Canterbury archives

Figure 2: Model of a Callender-Hamilton bridge.

The MacMillan Brown Library at the University of Canterbury holds 116 boxes of Hamilton material in their archives collection [7]. This collection contains many models, paintings, books, hundreds of photographs, and upwards of 20,000 documents that were donated by the Hamilton family in 2010. These date as early as 1882 and this is the first time that they have been inspected, summarised and documented. Figure 2 shows one of the many models that are part of the archival collection.

2.3. Opus International Consultants

In attempt to gain an understanding of the current Callender-Hamilton bridges in New Zealand, Opus International Consultants (formerly the Ministry of Works and Development) were contacted. They assisted with information about bridge management and maintenance, and located Callender-Hamilton bridges across New Zealand. Many of these bridges were visited over the course of the project.

2.4. Family members

The initial family connection is that Hamilton was the great uncle of the third author. Hamilton's daughter, Margaret Ritchie, gave some insight about her father's life, some background on the archives, and the patenting battle that consumed Hamilton's life for a number of years. Another of Hamilton's daughters, Mary Bliss, provided information relating to his life via email. His son Robert Hamilton provided supplementary information. Figure 3 shows a photograph of Archibald Hamilton, with his wife Bettina and their six children.

Figure 3: The Hamilton Family. L-R Mary, Robert, Archie, Margaret, Alex, Bettina, Janet, Bill

3. About Archibald Milne Hamilton

3.1. Early Life

Archibald Milne Hamilton was born and grew up in Waimate, South Canterbury, and was educated at Waitaki Boys' High School. He displayed keen interests in engineering from an early age, notably the development of transmission radio. At the age of 18, Hamilton had his own transmitting and receiving amateur wireless station and was potentially one of the first people in New Zealand to transmit wirelessly with London using Morse Code [10]. He imported and used the first thermionic valve in New Zealand in 1920, and won the University of Canterbury's Engineering Society Lecture prize, along with a colleague, for their paper on "Thermionic Valve in Radio Telegraphy".

3.2. University study

Hamilton graduated with a Bachelor of Engineering (Civil) from Canterbury College (now the University of Canterbury) in 1924. Whilst at university, pulmonary trouble prevented Hamilton following up electrical or radio engineering. Doctors advised him that an outdoor life would be suitable. He then decided to take up civil engineering and outdoor mountain surveying. While this proved an invaluable decision, curing him in the long run, he was not accepted for World War II service.

3.3. Graduate employment

Hamilton worked for the Lyttelton Harbour Board in 1924 and 1925. Along with Gordon Douglas White-Parsons, he constructed an exact scale model of the port, shown in Figure 4. They used this model to investigate troublesome wave action within the harbour. From the model they were able to make suggestions to the Board for improvements and enlargements. White-Parsons was a friend and colleague, who eventually assisted developing Callender-Hamilton bridges as an employee of the Callender Construction Company in London.

Figure 4: Model of the Lyttelton Harbour.

3.4. Career overseas

Over the next two years, Hamilton was employed by the Admiralty in London, where he worked on the development of Singapore's naval base. He was then appointed Assistant Engineer to the Public Works Department in Iraq, where he directed construction for the Rowanduz Road. This was a strategic route requiring major civil engineering feats on behalf of the British Empire from 1927 to 1932. It was here the Callender-Hamilton bridge design originated. He then worked alongside the British Military on bridging techniques and further developed his design before becoming a consulting engineer in London.

4. The need for new bridge design

4.1. Military bridging in World War I

An investigation by the Royal Engineers Society in England, analysing the various types of military bridges during World War I, showed various disadvantages in the bridging used by the British forces. There was a need for an increase in live loading and span length. It was also noted that the construction period was too great for effective assault.

4.2. The Rowanduz Road (1927–32)

The British Administration in Iraq gave Hamilton the job of constructing the Rowanduz Road. Described in Hamilton's book, *Road Through Kurdistan*, this went through Kurdistan between the northern Iraq and Iran borders [9]. The road's construction required many bridges crossing deep ravines along the treacherous countryside. Due to the lack of resources and skilled labour locally, the majority of these were built with surplus military bridges from World War I. Figure 5 shows a bridge in the Rowanduz gorge, Iraq. It can be seen the difficult terrain the construction team had to work with.

On this project Hamilton identified the need for an improvement in efficient bridge design and construction. He devised a concept of using standard sets of parts that could be fixed together in order to form different lengths [12]. The strength could then be varied by attaching further members.

Figure 5: A Military-style bridge.

As head engineer, Hamilton's life was fully occupied during the five year project. He was considered the father figure for up to 1000 workmen, who spoke seven different languages. Hamilton was in charge of looking after their pay, health and food requirements. This road became known as the Hamilton Road. Although he hoped it might unite the region's people it has been fought over many times [9]. Even by today's standards, this road is a considerable engineering feat and remains one of the region's most strategically important roads

Launching possibilities in cantilever form were broadened in the construction of the bridges, which used nothing more powerful than Trewhella tree pulling winches for erecting long span bridging [5]. The British military became particularly interested in this technique. The Trewhellas, which were easily carried by one or two men, later became standard for Ministry of Transport Callender-Hamilton bridge erection and also for righting Army tanks or trucks, or pulling them out of mud.

Hamilton was granted premature termination of his contract when the Rowanduz Road was completed. This enabled him to return to England and place his bridging experience and proposals before the War Department with a view to introducing a new military bridge. This would later become known as the Callender-Hamilton bridge.

5. A new bridge design

5.1. Requirements

Hamilton set the following goals for his design to achieve:

- As few members as possible
- A bridge form of any span and width to carry a range of loads
- Easy and cheap to manufacture with a high degree of accuracy and uniformity
- Light enough to permit easy transport
- Easy erection on site without the need for highly skilled labour or elaborate plant
- Fixing of any type of bridge deck
- Suitable for rapid dismantling, without damage
- The structure must permit a simple process of proportioning the members according to the stresses imposed by the system of loading.

5.2. Components

Each of the requirements had some influence on the design of the Callender-Hamilton bridge [6]. It is comprised of just 10 different parts, and the heaviest member is just 191 kilograms (kg) [15]. The range of spans was from nine to 61 metres (m) in the form of either a single or double truss, in a single or double tier.

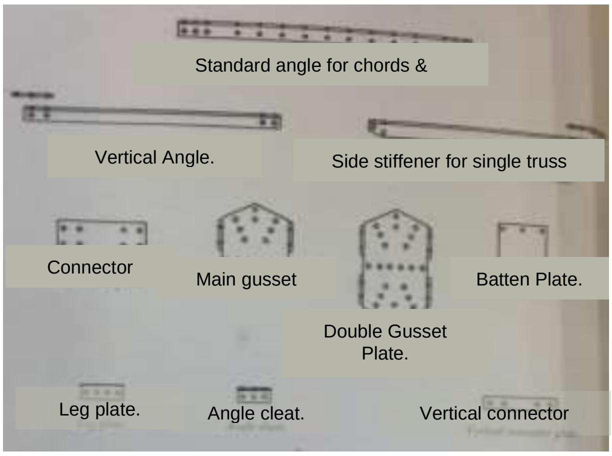

Figure 6: Standard Callender-Hamilton bridge parts

Figure 6 shows the standard members and gusset plates used for construction of the bridge. The bridges are formed together using bolted construction, eliminating any welding or cutting processes from site. This allows large structures to be broken down into smaller, lightweight, parts which are easy to handle and transport to site. The bolts were of standard type, 38.1millimetres in diameter.

5.3. Galvanizing and durability

The bridges were first designed to be temporary. The bridges could be deconstructed and parts used many times over. All members were hot dip galvanised after cutting, punching and drilling was complete. The combination of bolting and galvanised steelwork allowed a bridge to be deconstructed where the members could be re-used without the need to take precautions against corrosion. The maintenance and painting period was modified to 30 years in normal conditions, reducing operating costs. Figure 7 shows a section of a hot galvanised gusset plate, 20 years after exposure to the atmosphere and a few feet above the sea [5]. The bolt heads are only just beginning to rust.

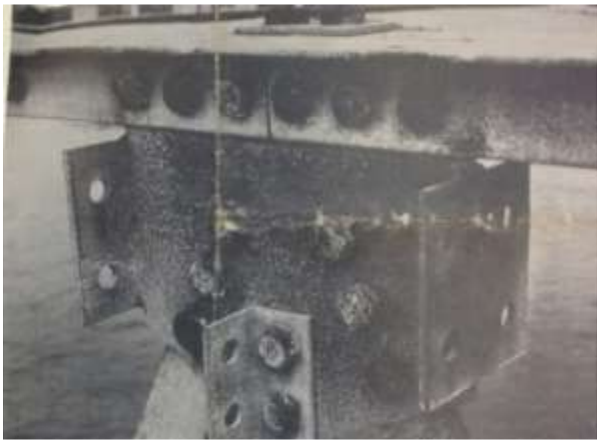

Figure 7: Gusset plate beginning to rust after 20 years.

5.4. Construction

One of the most remarkable things about the Callender-Hamilton bridge's design is the small amount of tools and equipment needed for assembly and erection (see Figure 8).

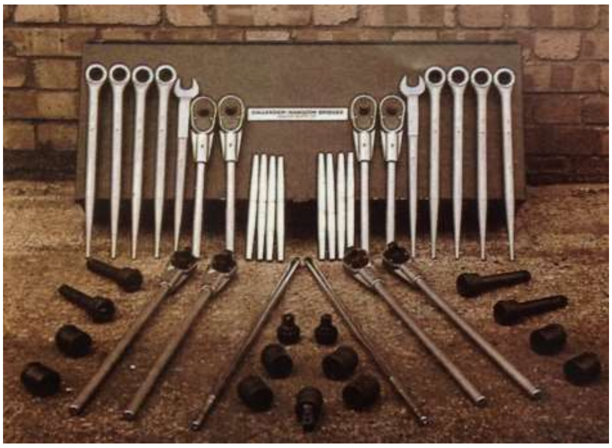

Figure 8: Standard tool kit.

For the majority of situations, all that was needed was a standard toolkit and some form of lifting system to use with the standard bridge parts. Therefore, temporary and permanent bridges could be installed within days using unskilled labour. This allowed the bridge to be used in a wide range of situations despite its simple design, which no other bridging system provided at that time.

5.5. Launching methods

The usual method for forming the spans was to first construct the bridge on the river or canyon bank by bolting together the standard bridge parts. The bridge could then be moved into position by sliding it along greased railway tracks. Figure 9 shows a Callender-Hamilton bridge during this operation.

Figure 9: Launching in progress.

The bridge could either be pushed as a cantilever with heavy weights on one end, as shown in Figure 10, or standard bridging parts could be used to build a tower and cables supported the bridge as it was pulled across. When heavy plant was available and the terrain allowed for it, cranes were used to lift the completed spans into place. Once in position the span was jacked down on to the end bearings.

Figure 10: A crane loading weights onto the bridge end.

6. Early stages of testing (1933)

6.1. Testing background

A test was conducted at the Experimental Bridging Establishment in Hampshire, England, in 1933 [6]. A 24 m bridge was erected to test the speed and ease of construction, and how the bridge would perform during live loads. The bridge was easily put together by just six men, who could handle the parts themselves and had no trouble lifting them into place with only hand pulleys. The bridge was then tested to see the effects of dead and live loads on the bridge parts. The setup can be seen in Figure 11.

Figure 11: Test bridge showing during live loading.

6.2. Performance during testing

The weight of the dead load, including the bridge and decking, was 37,200 kg. Loading consisted of scrap metal weighing 18,000 kg in the centre of the span. For live loading, tanks weighing 38,100 kg and 16,300 kg were placed as close as possible to each other at the centre of the bridge. The bridge performed better than expected with no failure occurring where the total loading on the structure was 72,600 kg.

6.3. Bending moment and shear curves

Modern computers now calculate bending moment and shear forces, but when Hamilton was developing the bridge this tedious process was done by hand. This information allowed military engineers to make quick decisions about the number of trusses required. An example of the chart for the test bridge can be seen in Figure 12.

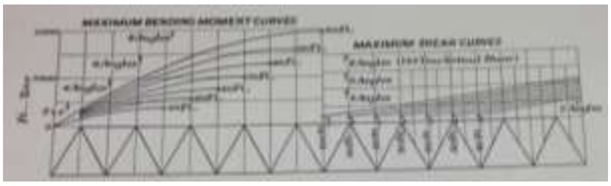

Figure 12: Maximum Bending Moment and Shear curves for the test bridge.

7. British military bridging

7.1. Prior to World War II

The need for improving military bridging was identified, and in 1932 a number of leading engineers were invited to send proposals to the Royal Engineers Society. The bridge design needed to cover a range of spans and consist of standard parts that could be easily assembled. It also had to be economical in weight, easy to dismantle and be capable of carrying the heaviest class of civil and military equipment [12]. However, no submissions were considered to be up to the British military's standard. Table 1 shows the specifications of the Callender-Hamilton bridge compared to the alternatives, where the range of spans was the largest along with the extremely light weight of the heaviest member [6].

Table 1: Military bridging options in 1933.

Bridge Type	Range of Spans (m)	No. of Parts	Mass of Heaviest Part (kg)
Mark II Truss	12 - 21	15	1,334
Inglis	18 - 33	6	408
Box Girder	10 - 29	2	590
Hopkins Light	23 - 32	22	472
Hopkins Heavy	32 - 46	22	472
Callender-Hamilton	9 - 61	10	191

7.2. During World War II

Advances on the Callender-Hamilton design had been made by Donald Bailey. The Bailey bridge's design allowed for a rapid erection time, although it was not as strong and robust as the Callender-Hamilton bridge. This meant that the Bailey bridge was used for assault bridging, while the Callender-Hamilton bridge was used for semi-permanent bridges along supply routes. Both designs gave the British Army a lead over any other country in this field at the outbreak of World War II. The simple manufacturing process, assembly and transportation made them ideal designs to use [12].

As there was such high demand for these types of bridges during World War II, there were many different factories producing parts. The components were manufactured in the United Kingdom (UK), India and South Africa from 1938 to 1945. For quality assurance, a test bridge was set up in each factory to ensure all the parts fitted requirements. While a test bridge was being assembled, it was being dismantled at the other end and then the approved parts were stored or dispatched as required.

As the bridge was made up of a number of standardised parts, members could be replaced singularly, rather than replacing an entire bridge. Figure 13 shows a damaged Callender-Hamilton bridge awaiting repair.

Figure 13: A damaged bridge during World War II

7.3. Current military bridging

The bridge design for the military has progressed to the Medium Girder Bridge. This meets the original specifications from the Callender-Hamilton and Bailey bridges, but advances have been through the use of modern-day materials. This bridge can be constructed in just 20 per cent of the time [16].

8. Patenting

Hamilton obtained two patents for his work on bridge design and construction. British patent no. 423926 details one form of multi-truss multi-tier bridge, while patent no. 423996 applies to particular construction methods used in Callender-Hamilton bridges. He also obtained patents in a number of other countries for his bridge designs.

8.1. Similarities with the Bailey bridge

After acknowledging Hamilton's work in 1933, an advancement of the Callender-Hamilton design was made by Sir Donald Bailey, the designer of the more well-known Bailey bridge [4]. Hamilton and Bailey had both been working with the British Military at the time. However, major patenting issues arose when a large military bridging contract was awarded to Bailey.

Throughout New Zealand and the world, Bailey bridges are still used in emergency situations as well as temporary solutions for planned events, such as roading projects. This Bailey bridging system is still regarded as a versatile, cost effective and easy short term solution, but without the advancements made by Hamilton the Bailey bridge may have never existed. Figure 14 shows a Bailey bridge, where the pre-fabricated sections are in 3 m lengths.

Figure 14: Bailey bridge [11]

8.2. Ex-Gratia awards

The influence that Hamilton's design had on this style of bridging had not been recognised by the military. Following the Callender-Hamilton design, three more multi-truss multi-tier designs appeared for military purposes, and Hamilton applied for an ex gratia award to acknowledge his innovation. In the application, Hamilton explained that current and future multi-truss multi-tier designs will look to his as the prototype that can be readily varied in form but not in principle.

After formal investigations into Hamilton's work advancing military bridging, he was awarded ex gratia awards in 1936 and 1954 to the value of £4,000 and £10,000 respectively for patent breach. However his daughter, Margaret explained that at the time there was an extremely high tax rate of around 90 per cent for this type of payment, and Hamilton was left with just enough money to buy himself a new Land Rover.

9. Production and evolution

In the 1950s there were over 1000 Callender-Hamilton bridges across 50 countries, stretching more than 17 km in length. The longest bridge of this design is 737 m, located at Haast on the West Coast of New Zealand.

9.1. Manufacturing

Hamilton signed a contract with British Insulated Callenders Cables Limited (BICC) [5], which is where the first part of the bridge name originates. There was an agreement on the royalties Hamilton would receive, based on the weight of bridging manufactured. The current bridge design in the UK is managed by Balfour Beatty Power Networks Division, the successor of BICC [3]. The bridge design in North America and Canada is managed by Acrow Limited of Canada [1].

9.2. Types of Callender-Hamilton Bridges

Callender-Hamilton bridges could be proportioned to satisfy a large variety of requirements. Apart from permanent bridges carrying utilities, foot traffic, road vehicles or trains, they were also required at short notice to meet short term emergency needs. In this case, they provided a substitute for a complete or partial failure of an existing bridge and temporary access during construction of another bridge. These short term bridges could be used following failures due to flooding, for advancing military units or repairs after the bombing of an existing bridge.

10. Callender-Hamilton bridges in New Zealand

Opus International Consultants (formerly the Ministry of Works and Development) are the bridge consultant for 11 of the 14 regions across New Zealand. Other consultants across the country include Bloxam Burnett & Olliver for Taranaki and Manawatu, Beca for Tauranga, while the Waikato region is shared between the two consultants (Waldin, 2013, pers. comm.). These consultants conduct the maintenance on all bridges within their regions.

There are 16 Callender-Hamilton bridges in New Zealand which are all located on State Highways in the South Island. Figure 15 shows the locations of these bridges.

Figure 15: Callender-Hamilton bridges in New Zealand

10.1. Choice of Callender-Hamilton Bridges

The Ministry of Works chose the Callender-Hamilton bridge design because of the low maintenance cost, due to the galvanised steel [14]. The standard design also allowed for simple construction and ease of transport [8].

10.2. Maintenance

The Callender-Hamilton bridges on the West Coast were constructed as early as 1955 and have lasted over 40 years without a paint job due to the hot dip galvanising of the members and bolts. This is impressive, especially considering the intense rainfall in the area and its proximity to the sea. Regular maintenance is done on the bridges, with an approximate value of $5000 per year spent on each bridge's expansion joints and plates. Impact damage is relatively regular with the Callender-Hamilton bridges compared to other bridges because they are narrow structures and a number have overhead bracing, such as the Gates of Haast bridge. Regular and routine maintenance is conducted on all bridges in the region, focusing on the pavement, waterway issues, clearing debris and general cleaning.

10.3. Replacement

No Callender-Hamilton bridges in Canterbury or the West Coast have been replaced as of yet. However, the Gates of Haast Bridge on SH6 is on a replacement program because of the area's risk of large slips, rather than the condition of the bridge. Some bridges have had seismic strengthening and many require upgrades to support heavier live loads. These bridges are only likely to be replaced where there are multiple reasons for replacement, such as road width, live loading, impact risk/damage or seismic risk/damage.

10.4. Bridge management

Opus follows a strict bridge management regime and the procedures are listed below:

- Visual/Superficial inspections every year to inspect any issues visible from the road.
- General inspections every two years to identify any visual defects
- Detailed/special inspections every six years with specific needs for different bridges
- Steel inspections and testing as required.

The bridge reports and maintenance needs are put into a database following each inspection with the likely cost and priority for component replacements. Based on the funding that the New Zealand Transport Agency (NZTA) supplies, repairs and strengthening work are then carried out. Designs for repairs are then tendered out to local contractors.

10.5. Case study

During the project, Jeremy Waldin raised a concern regarding three single truss Callender-Hamilton bridges with spans greater than the previously assumed maximum length of 27 m. Unknown to Opus, the design manual had been updated, and the true maximum span was 37 m. This information from the archived papers and technical drawings were relayed to help Opus with the management of these bridges.

10.6. Emergency bridging in New Zealand

The NZTA has approximately 3 km of Bailey bridging available for hire in 3 m lengths [11]. The Bailey bridge is favourable in this instance due to the quick erection time. A temporary single lane 30 m span can be erected and in use within one week of ordering. They may be used as a temporary replacement due to failure, temporary structures for construction projects or provide crossings for other non-emergency situations.

11. Conclusions

The first Callender-Hamilton bridge was constructed over 80 years ago following Archibald Milne Hamilton's pioneering work in the field of civil engineering. He expanded the boundaries of what was possible with pre-fabricated bridging and was able to greatly assist the British Military with his innovative design and construction methods.

Hamilton made a significant contribution, not only World War II military bridging, but to the future of standardised bridges around the world. A number of Callender-Hamilton bridges are still in operation in New Zealand and elsewhere in the world.

After reviewing the collection of archives, as well as a number of other resources, the origins, design and development of this revolutionary bridge were acknowledged and recorded in this student project.

12. Acknowledgements

Special thanks are made to Archibald Hamilton's family for making their father's resources available to the Macmillan Brown Library at the University of Canterbury, Christchurch. Additional information on Hamilton's life was provided by Mary Bliss, Margaret Ritchie and Robert Hamilton.

Acknowledgements also go to staff at the Macmillan Brown Library, for their efforts and continued support. The initial acquisition was arranged by Jill Durney and Jeff Palmer, and the current research was greatly assisted by Erin Kimber, Head Archivist.

Support from industry included Russell Nicholls, Project Manager at Opus International Consultants, Dunedin, who provided information on locations of Callender-Hamilton bridges across the South Island, and Jeremy Waldin, Senior Bridge Engineer at Opus, Christchurch, for providing other locations across New Zealand, and information on Opus's bridge management.

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THE FOUR R'S – REDUCE RISK, RAISE RESILIENCE: LOCAL AUTHORITY PRIORITIES AND THE AUCKLAND PERSPECTIVE ON ENGINEERING REQUIREMENTS FOR HERITAGE BUILDINGS

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Abstract
This paper describes Auckland Council's roles and responsibilities in ensuring that the engineering of our heritage buildings is to levels of safety required legally and by the Government, the council's own policies on building safety as an employer, and as a kaitiaki of publicly accessed heritage places. The paper describes the level of investment required to achieve these aims as a regulator and a large portfolio holder, and examines the tension between this, the level of risk in relation to different types of natural events, and the need to represent the values and interests of its citizens and ratepayers. There is ultimately a need to consider whether the costs associated with retrofitting heritage buildings are proportionate to the risk of fatal harm from a seismic event, or indeed whether there are other, greater risks, or even more common reasons for undertaking such works.

1. Introduction

Local authorities have a statutory responsibility to develop policies and strategies on responding to natural disasters, chiefly at this time focused on the response to earthquakes and how buildings perform safely in a seismic event. For many, the 2010–2011 Canterbury earthquakes raised concerns over the safety of our places of living, and of work or public interaction. Councils across the country have had to respond to the reaction to the earthquakes, and the corresponding recommendations of the Government. Much of the focus has been on buildings of pre-1976, and particularly pre-World War 2, construction. These have a greater likelihood to be considered earthquake prone or possess associated hazards that could pose a reasonable risk to the public during a seismic event. Auckland's greater stock of heritage buildings falls largely into this "at risk" grouping, including many that are public buildings and places of employment for Auckland Council staff. The council has a responsibility to ensure private individuals and institutions are aware of, adhere to and uphold Government legislative requirements. At the same time, we as employers and custodians (kaitiaki) of treasured places need to ensure that we lead by example in the provision of safe places to work and the good management of heritage places.

2. The council roles

The council has three main roles with regard to heritage buildings in Auckland. These are:

- Regulator – of Building Act and Resource Management Act provisions;
- Owner – of a significant portfolio of heritage buildings and places of significance; and
- Advocate – through the Auckland Plan in particular, and through the grant support of maintenance works to privately owned heritage buildings in the Auckland Region.

A fourth role could be considered in the context of a major event, and that is the council as the lead role of civil defence provision and organisation. Many heritage buildings in Auckland are also public buildings, and include community halls and churches or other locations that become the focus for civil defence response in the event of a natural disaster or other crisis. The resilience of these buildings is important therefore, not just for the protection of heritage assets, but also to provide continuity of functions following a major incident, such as was observed at Canterbury.

The roles of regulator and portfolio owner could be considered to focus on the reduction of risk in relation to fatalities arising from environmental hazards, while the roles of advocate, and of a coordinator of civil defence, can be seen to focus on the importance of providing resilient places for communities to rally around.

2.1. Regulator

Seismic assessment procedures formally utilised in New Zealand entail a scoring system of percent New Building Standard (%NBS) as proposed by the New Zealand Society of Earthquake Engineering [17]. This indicates the expected capacity of the building as a percentage of the ultimate limit state (ULS) demands prescribed by current standards [16]. The phrase "new building standard" is indicative of the intent of the scoring system - a building that is assessed as having a resistance exceeding 100%NBS is expected to withstand the current ULS "design basis earthquake" (DBE) demands, whereas a building assessed at 34%NBS is expected to withstand only one-third of the DBE. A building with a score of less than 34%NBS is deemed potentially "earthquake prone" and may be subject to regulatory measures per the Building Act [14] and current Auckland Council policy [4], warranting further assessment and possible structural retrofit.

Auckland Council is responsible, under the provisions of the Building Act [14], for ensuring that all commercial buildings and residential buildings subject to the provisions (two or more, and multiple occupancy units) are subject to an assessment of their likely seismic performance. This obligation has been made operative in Auckland by the council deciding to themselves undertake initial seismic assessments on all aforementioned buildings of pre-1976 construction, Post-1976 buildings are not likely to be earthquake-prone in Auckland due to low seismicity and more modern design standards, and are therefore reasonably excluded except where a known design deficiency is identified by the technical community.

To date, Auckland Council Building Control has assessed close on 6000 pre-1976 commercial and large residential buildings within its jurisdiction, and estimates that there may be another 6000 yet to do. Of that total, just over 700 have so far been indicated as potentially earthquake-prone, and forecast estimates put the final number somewhere around 2000-2500 total, although changes to the NZSEE assessment guidelines [17] being used for those may have a noticeable impact on that final figure. It has taken since mid-2011 to carry out this number of assessments and distribute them to owners for discussion before they become part of the public record. The estimated cost for this work to date has been put at $1.5 million.

Alongside the development and implementation of an operational programme for seismic performance assessments, Auckland Council has also been significantly active in regard to developing appropriate policy for the region on earthquake-prone buildings, and in discussing changes to legislation and resulting policy and operational methodologies with the Government. We have made submissions to, and presented before, the Canterbury Earthquakes Royal Commission of Inquiry, the Ministry of Business, Innovation and Employment, and to the Parliamentary Select Committee on the Building (Earthquake-Prone Buildings) Amendment Bill. We have also developed and published guidance material for the general public to improve awareness on what this work is about, and advocate strongly for more work to be done nationally in that regard.

2.1.1. Typologies of heritage buildings in Auckland

Of Auckland's heritage buildings potentially subject to the provisions of the Building Act, the majority are constructed using timber or unreinforced masonry (URM) techniques. Auckland's building industry was well served historically by timber (Kauri Logging being a major industry until the 1930s), and clay manufactured products (though no Auckland-based producers now survive). Materials and practices initially closely followed those from the United Kingdom or wider British Empire, and up until the 1960s materials such as steel were regularly imported from the mother country for use in Auckland's construction.

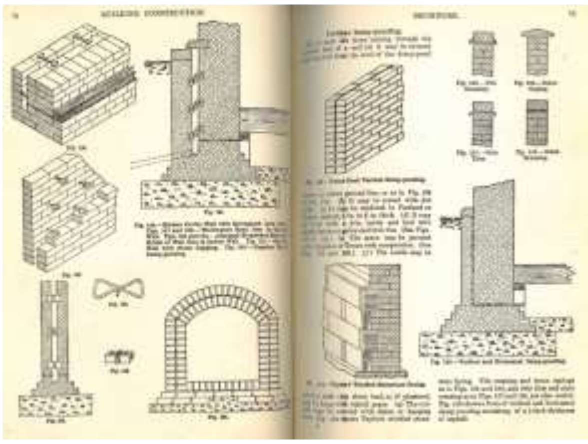

Figure 1: Traditional brick cavity wall construction methods (After Adams [1], 72f).

The construction of ceramic masonry buildings usually means the use of machine-pressed brick, the performance of which can probably be assessed as reasonably consistent, when compared to traditional hand-made stock bricks. One element to consider when assessing URM buildings, however, is the relative sizes of the units and the use of different types of brick in different areas of the structure. A cautionary note of advice is provided by a 1901 textbook on *Advanced Building Construction* [3]:

> Evils of facing with superior bricks.- It is a common practice, especially in using single Flemish bond, to build the face work with better bricks, and with thinner joints, than the backing. This leads to unsound work, and should not be allowed. In such cases, on account of the joints of the backing being thicker than those of the face work, the courses will not be of **same** in front and back. For example, it may require eight or nine courses of the face to gain the same height as six or seven of the backing (see Fig. 89) and it is only when they happen to come to a level as at aa (once in every eight courses or so), that headers can be introduced. Even the few that can thus be used are liable to be broken off by the inequality of settlement, caused by the difference in the thickness of the joints. This may be partly remedied by using thinner bricks in the backing so as to have the same number of joints in the

face and back; but even then the difference in the thickness of the joints in facing and backing tends to cause unnatural settlement, unless the work is built in very quick-setting mortar which will harden before any weight comes upon it. A further result of this practice is that, in order to economize the more expensive face bricks, dishonest bricklayers will cut nearly all the headers in half, and use "false headers" throughout the work, so that there is a detached slice, 4 ½ inches thick, on the face, having no bond whatever with the remainder of the wall.

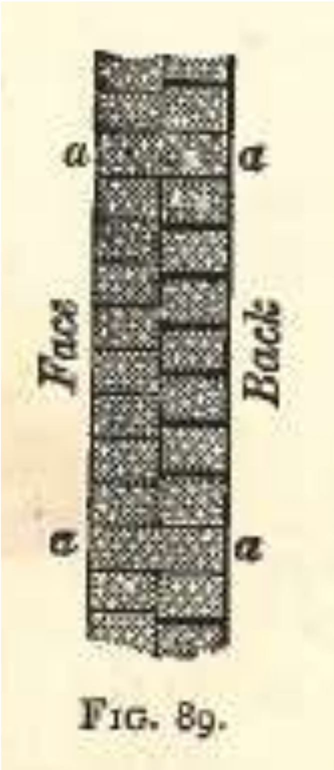

Figure 2: Description of poor building practice with facing bricks (after Burrell [3], 56).

Other proprietary systems were developed by the pioneering clay bakers. Clark's brickworks manufactured salt-glazed, hollow ceramic blocks for use as masonry units. Warkworth Town Hall is one of the few surviving buildings constructed with this unusual and challenging material, and forms the subject of our engineering case study – Strengthen, Remodel or Demolish? A Council Perspective on engineering retrofit in the historic portfolio.

Figure 3: Wellesley Street, Auckland; example of typical cross-section of an Edwardian URM building. Note the irregular coursing and variable mortar joints resulting from use of facing bricks (19 courses to top of column) and commons (20 courses to top of column) behind.

Stone masonry buildings are less common in Auckland, and statistically are perhaps not as significant from an engineering perspective. A handful of commercial stone buildings still survive, usually utilising local basalt; perhaps more relevant are the 'high architecture' projects, such as St Paul's Cathedral and Auckland War Memorial Museum. These structures do not typically represent our engineering retrofit scenarios. Conversely, the 'public good' of these places is self-evident and easy to defend in terms of costs.

By and large, Auckland historically is a city of timber, and brick, and to a lesser degree steel and concrete. These then are the essentially modest structures that nevertheless create the Victorian and Edwardian core to our city. They are not all formally protected, but are all redolent of a pioneering age, the spirit of which Aucklanders are in the main desirous to maintain.

One area where local innovation may have had more significant impact was in the manufacture of cement and reinforced concrete products. From the late 19th century reinforced concrete was being developed as a construction material, and is adopted quite widely and relatively early in Auckland. Often referred to as ferro-concrete (the Ferro-Concrete company of Australasia constructed the Grafton Bridge and Queen's Wharf) the material was used for infrastructure as well as commercial buildings. Grafton Bridge, for example, was considered at the time of its construction to be the longest reinforced concrete span in the world. This led to the construction of some ‘composite’ buildings with reinforced concrete structures, containing brick cavity panels. The performance of this material has not been such a focus of Auckland Council’s work to date, and is to some degree a reflection of the main construction typologies present in the Council’s own portfolio (see Figure 8).

Auckland is the largest city in New Zealand, and because of the relative prosperity of Auckland during the period 1880–1935 when most URM buildings were being constructed, the city has the greatest stock of URM buildings in the country. Aspects studied while assessing the hazard posed by these buildings include:

- The number, location and age of these buildings, and the role that these buildings play in the built heritage of the city
- Their architectural attributes and material characteristics
- Earthquake prone building policy and other public legislation relevant to these buildings
- The seismic hazard in Auckland
- The expected performance of these building by extrapolating observations from the recent Canterbury earthquakes
- Past and current activities to earthquake strengthen Auckland’s URM buildings, at both an owner and regional territorial level.

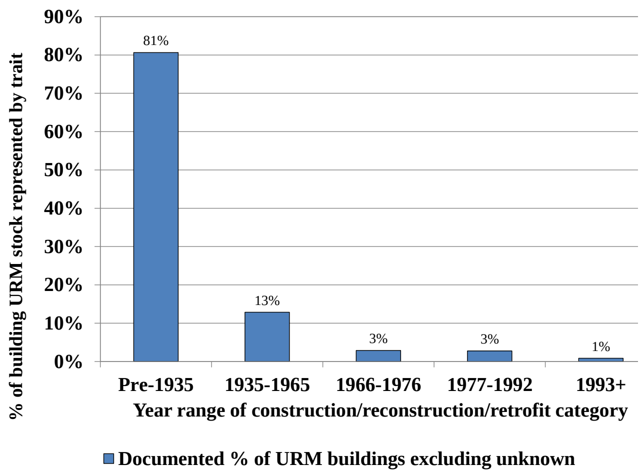

Figure 4: Proportions of documented non-domestic URM buildings in Auckland by year of construction, reconstruction, or seismic retrofit (after Walsh et al [21]).

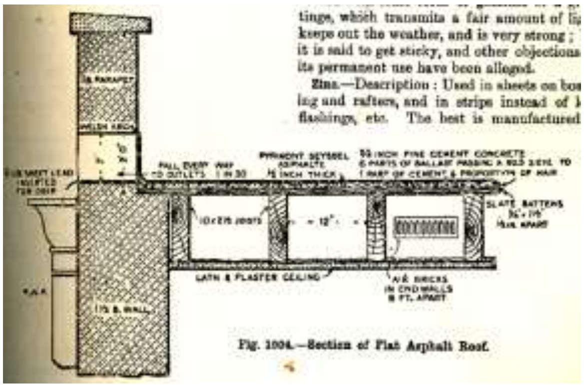

Figure 5: Typical cross section of a URM parapet and timber-framed roof diaphragm (after Adams [1], 261).

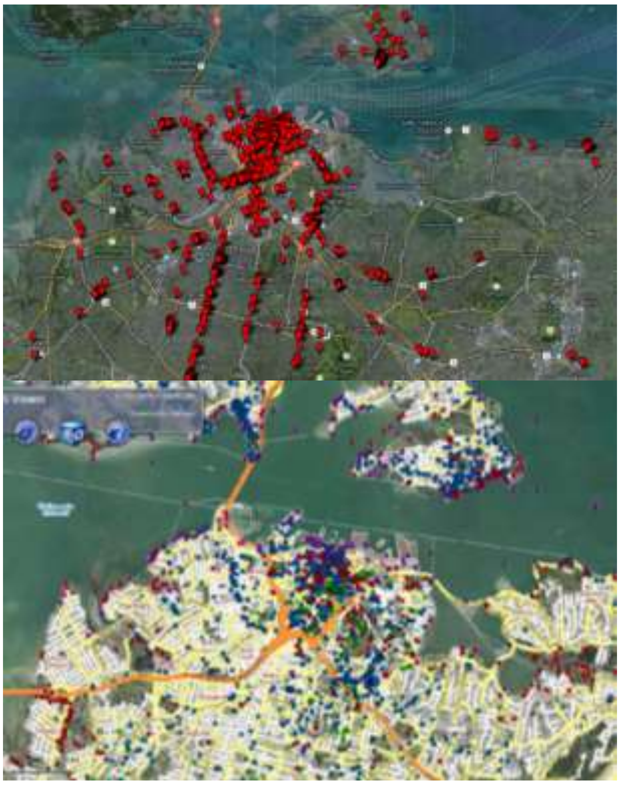

Figure 6: comparison between Earthquake-prone buildings identified in IEP process (red dots - top figure) and historic buildings identified on Auckland Council Cultural Heritage Inventory (blue squares bottom image)

2.2. Owner

As an owner of approximately 3500 buildings, including several constructed of URM, the Auckland Council Property Department (ACPD) began a seismic retrofit prioritisation programme in 2012. The intended result of this programme is a prioritisation framework which will categorise all council buildings in accordance with their seismic risk and council-assessed value in order to assign resources efficiently and effectively to both seismic inspections and future retrofit work. The programme will produce a methodology as well as a list of properties and a timeline for construction work. Corollary outputs will include a
detailed, standardised inspection programme to be used by the Departments of Property and Building Control, as well as a standardised database index

system to be used across departments to aid in data procurement on current and future property projects. Furthermore, a strategic plan for building asset priorities is expected to be delivered to the executives of Auckland Council and referenced by other departments as part of their planning processes.

In addition to the requirements for buildings assessed with a seismic score of less than 33%NBS, a building with a score less than 67%NBS is deemed potentially "earthquake risk" and may be subject to the provisions of the Health and Safety in Employment Act [13]. Council has responsibilities under the Act to take all practicable steps to reduce risk in all workplaces (through structural enhancement and/or safety training) for which it is the employer, the entity in control of the workplace, or the principal (in regard to contractors and subcontractors) [19], [10]. These items are summarised in Table 1. Note that calculated risk levels are not proportional to the %NBS scoring range, as a building determined to have a score of 33%NBS is assumed to have a collapse or partial collapse risk that is approximately ten to twenty times higher than a building rated at 100%NBS [17].

Table 1: Associated values and implications of seismic assessment %NBS scores (after Walsh[21])

%NBS	EQ risk category	Potentially affected by Building Act (2004) and Council Policy (2011)	Potentially affected by Health & Safety in Employment Act (1992)	Non-compliant with current NZS (2004) loading standard
< 20	Prone	X	X	X
20 to 33		X	X	X
34 to 66	Risk		X	X
67 to 79	Low risk			X
80 to 100				X
> 100	Presumed to comply with current loading standard			

2.2.1. Managing large portfolios

Auckland Council manages the largest Local Authority portfolio of heritage buildings in the country. Nationally, other portfolio holders on this level are the Ministry of Defence, Department of Conservation, the Government estate and Housing New Zealand which all maintain large portfolios with significant numbers of heritage buildings, to a varying degree affected by the proposed amendments to the Building Act.

2.3. Advocate

The council role as an advocate for heritage buildings is strongly based around our strategy developed in the Auckland Plan, which **are** based on three principle drivers:

- Understand, value and share our heritage
- Invest in our heritage
- Empower collective stewardship of our heritage

Our actions around this include systematic survey of the Auckland Region to identify historic heritage places, to provide advice on consent applications relating to scheduled places, and to 'lead by example' in the care of our heritage portfolio. To this end, we have initiated a 'seismic exemplar' project, working with the Waitemata Local Board, Auckland University Engineering Department and locally experienced engineering teams to cost and implement retrofit solutions to different levels of code, and provide the learnings from that work to local business owners.

In a more practical sense, Council leads by example in the attitudes and approaches it takes to the heritage assets within its own portfolio. These rarely, however, include planned upgrades to heritage buildings in their own right, but are usually part of a broader adaption or upgrade of buildings whose primary function is the provision of public services in one form or another. Recent completed examples since the creation of the single Auckland Council include the Tepid Baths (swimming pool), Lopdell House and Art Gallery (arts and culture), and Shed 10 on Queen's Wharf (events and cruise ship terminal). Further upgrades are planned or commencing at Mt Roskill's former municipal building, Warkworth Town Hall (community and local board services), and the Ellen Melville and Pioneer Women's' Hall in the CBD (community services). The pattern that emerges here is clear – the level of use and function of places is critical to attracting the necessary budget to undertake such works. It is worth noting that there is no capital fund for upgrade purely allocated on the basis of heritage value alone.

3. Measuring risk and measuring value

3.1. Auckland's seismic hazard

Risk is the product of three components – hazard, vulnerability, and consequence. Regarding the risk component of hazard, the islands of New Zealand sit roughly along the boundary of two of the planet's lithospheric tectonic plates – the Australian Plate and the Pacific Plate, resulting in all of New Zealand having a moderate to severe seismic hazard relative to a global scale. The Pacific Plate subducts beneath the Australian Plate alongside the east coast of the North Island at an average rate of approximately 50 mm/year [11]. The Auckland region's seismic hazard is low relative to the rest of the country because Auckland resides further from this subduction zone, approximately 300 kilometres (km), than most other cities and towns in the North Island,.

Much of South Auckland's geology, especially along the west coast, is comprised of Pleistocene to Holocene marine and alluvial sediments and dune sand [12]. Where unconsolidated, these soil types are prone to amplifying earthquake intensities up to two Modified Mercalli (MM) levels higher than intensities on neighbouring rock [6]. Fortunately, much of Auckland Central rests on volcanic and sedimentary rocks. Furthermore, liquefaction and lateral spreading are not likely to affect much of the region during an earthquake [5], although slope instability during seismic shaking could damage buildings across Auckland [6].

The only two faults near Auckland active in the past 125,000 years are the Kerepehi and Wairoa Faults [9], [6], in the South region. The Kerepehi Fault is located in the centre of the Hauraki Plains approximately 75 km from Auckland Central [9], [6], displaces approximately 0.13 mm/year [6], contributes approximately 2% to the 500-year peak ground acceleration (PGA) determination [18], and has a mean earthquake return period of 2500 years [9], [6], with a moment magnitude M_w 7.2 [18] capable of producing a shaking intensity of MM7-MM9 throughout the region [9], [6].

The Wairoa Fault (technically, separate North and South faults) is located near the Hunua Ranges approximately 35 km from Auckland Central, displaces approximately 0.1 mm/year [6], contributes approximately 4% to the 500-year PGA determination, and could produce an earthquake with a moment magnitude of M_w 6.7 [18]. However, distributed seismicity sources account for the majority of contribution to the determined 500-year PGA in the Auckland region [18], and these sources account for earthquake occurrences on currently unknown faults based on a nationwide distribution of seismic hazards [5]. Hence, the next intense earthquake in Auckland is considered more likely to come from an unknown or buried fault than from a known fault.

3.2. Vulnerability of historic buildings to earthquakes

The experiences of the 2010-2011 Canterbury earthquakes have demonstrated that there are certain characteristic reactions from, in particular, historic URM buildings (see Figure 7) that require an engineering response. These are:

- the reaction of URM walls to out-of-plane demands;
- the collapse of heavy elements resulting from traditional architectural practice and construction techniques (e.g., parapets and chimneys);
- The behaviour of double-skinned (cavity wall) construction compared to solid wall construction; and
- The behaviour of buildings of inconsistent geometries adjacent to one another (differential vibration, otherwise referred to as pounding).

(a) Building A parapet condition in October 2010

(b) Building A parapet condition in March 2011

(c) Building B facade condition in October 2010

(d) Building B condition in March 2011 – collapse of facade

(e) Building C post-22nd February 2011 – collapse of outer leaf of cavity wall

(f) Building C post-13th June 2011 – collapse of inner leaf of cavity wall

Figure 7: Post-earthquake observations of out-of-plane failures to URBM buildings in Christchurch (after Walsh et al. [21]).

3.3. Other risks

While there is great focus, and not without reason, on the potential risk of building collapse from earthquake activity, it is accepted that the probability of an earthquake event of sufficient magnitude to cause the type of damage witnessed during the Canterbury earthquakes is less likely than other major environmental risks, such as typhoon, flooding, landslide or tsunami. A geological event more likely to occur might be volcanic (according the Auckland Council Civil Defence website there is an 8% probability of such an event over an 80 year period), yet there is no requirement to retrofit or design new buildings for ash-loading from such fallout. The psychological difference is this – the Canterbury Earthquakes *occurred.* What was a risk became an actual event, with consequences.

More frequent, as part of the regular cycle of things, are the effects of inclement weather, particularly high wind, on ineffectively maintained buildings, or other risks such as fire damage or vandalism. The greater geographic area of the new Auckland Council is rural, with many isolated places of historic value that are prone to anti-social behaviour, at risk from arson, or difficult to maintain. Prior to the Canterbury events, owners could mitigate the risk of such events through a standard insurance policy

3.4. Auckland Council's heritage portfolio and its exposure to the consequences of earthquakes

Auckland Council has a statutory responsibility to recognize and provide for the protection of historic heritage under the following Acts:

- The Health Act 1956;
- Burial and Cremation Act 1964
- Protected Objects Act 1975 (formerly known as the Antiquities Act);
- Reserves Act 1977;
- Conservation Act 1987;
- Resource Management Act 1991;
- Historic Places Act 1993;
- Local Government Act 2002; and
- Building Act 2004.

These Acts, as well as local policy, require Auckland Council to meet relevant statutory requirements for land it owns and administers, to obtain relevant Heritage New Zealand archaeological authorities for any work that may affect an archaeological site, to work within the Auckland Plan's strategic directions, directives and actions, and to lead by example when it comes to heritage protection. Auckland Council owns heritage properties through a number of means:

- Purchased for protection;
- Gifted to council;
- Built Heritage Acquisition Fund;
- Built for public service but become "heritage"; or
- Acquired for other purposes.

As of September 2014, Auckland Council has identified 217 buildings recognised as "heritage" with either Heritage New Zealand or the local authority. The estimated capital value of these buildings is almost one billion dollars (although one building – the Civic Administration Building on Greys Avenue – accounts for approximately 15% of that total). These heritage buildings accommodate a variety of council service functions, as well as house commercial tenants, as summarised in Table 2.

Table 2: Summary of functional uses being offered in heritage buildings owned by ACPD.

Functional uses	# bldgs	Avg. floor area (m^2)	Estimated total floor area (m^2)
Arts/Museum/Cultural Centre	6	880	5,280
Cafe/Restaurant	4	160	640
Camp/Hut/Lodge Building	3	?	-
Chapel/Crematorium	2	109	218
Childcare Facility	1	320	320
Commercial/Investment Building	23	1192	27,418
Community Centre	3	562	1,685
Community Facility	33	376	12,413
Community Hall	22	358	7,885
Community House	7	278	1,949
Council Office/Service Centre	8	7508	60,067
Farm Building	9	236	2,128
Fire Station	1	?	-
Library	6	624	3,744
Public Toilet/Changing Shed	24	45	1,087
Residential	41	787	32,256
Residential Garage	2	?	-
Sports Facility	6	280	1,678
Stadium/Grandstand/Arena	1	990	990
Swimming Complex/Aquatic Centre	2	1655	3,310
Visitor/Information Centre	2	?	-
Works Depot/Utility Building	7	318	2,223
Mixed Use	4	880	3,518
Total	**217**	**778**	**168,808**

Of the 217 heritage buildings owned by ACPD, 29 (13%) have been assessed as potentially "earthquake-prone" using either a preliminary or initial assessment method, 46 (21%) have been assessed as potentially "earthquake-risk," 12 (6%) have been assessed as either "low risk" or "compliant," and the remaining 130 (60%) have not yet been assessed. However, most of the buildings not assessed are buildings with low importance levels (e.g., toilets and infrequently occupied facilities) or buildings known to be constructed of timber framing (see Figure 8), so most are unlikely to be "earthquake prone." Nonetheless, the ACPD heritage portfolio is likely to have more seismically vulnerable buildings and building components (e.g., chimneys and parapets) than the Auckland non-domestic building population at large, given the relative age of the buildings in the portfolio. In Figure 9, the buildings are grouped into ranges of years of construction consistent with major updates to the loading standard and with previous typological groupings used in New Zealand [17], [20], and [7].

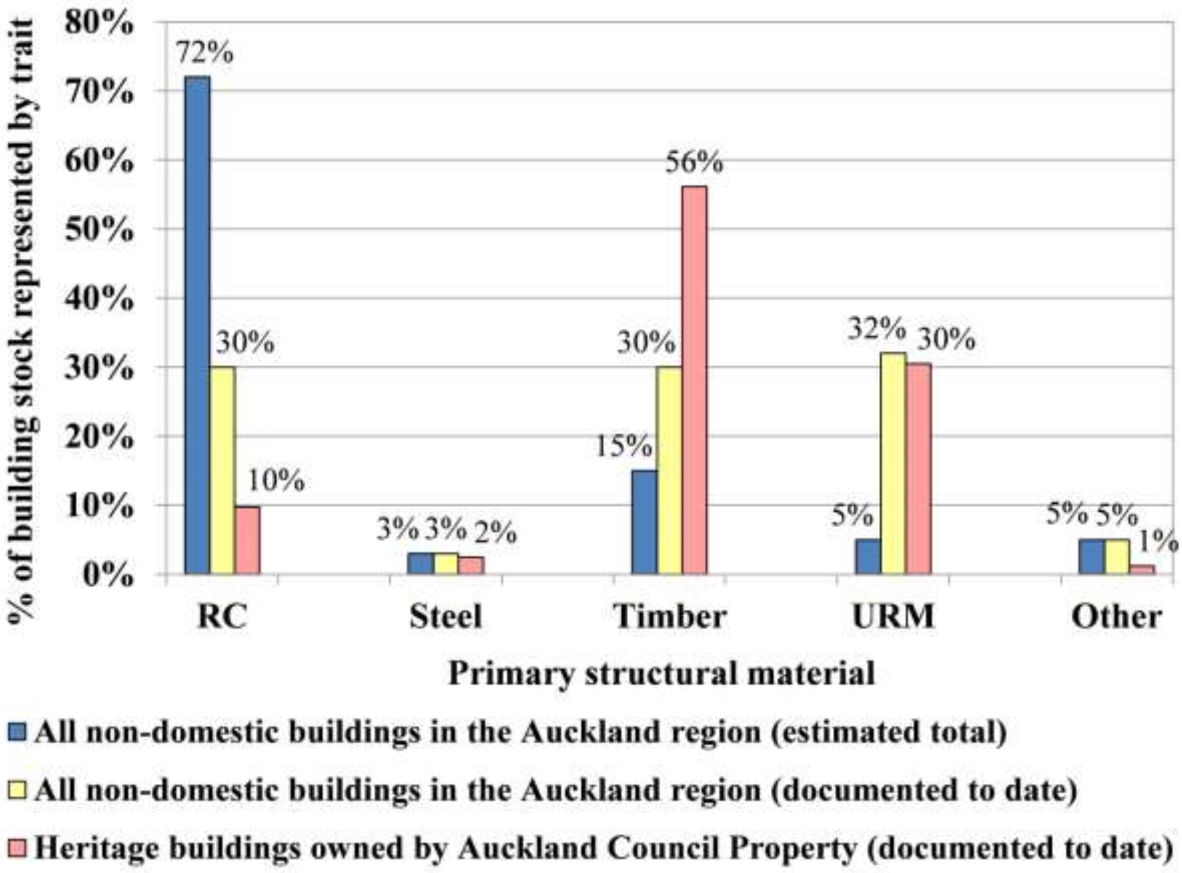

Figure 8: Proportions of estimated and documented non-domestic URM buildings in Auckland by primary structural material type.

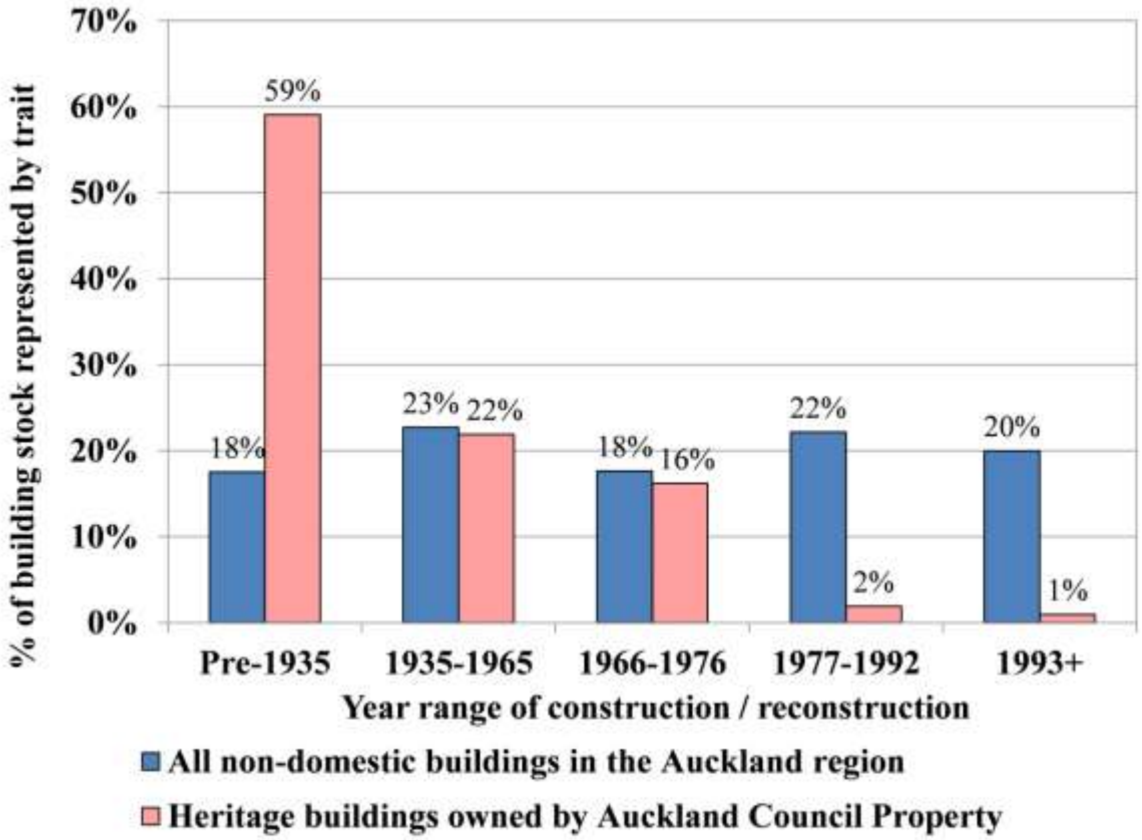

Figure 9: Proportions of documented non-domestic buildings in Auckland by year of construction or reconstruction.

3.4.1. Strengthen, remodel or demolish? A council perspective on engineering retrofit in the historic portfolio

Warkworth Town Hall was originally constructed in 1909, using a system of hollow, salt-glazed ceramic bricks patented by the Clark Brickworks, Hobsonville. The block was a large hollow rectangular brick with a vertical divider and was the precursor to the modern concrete block technology. This construction form is locally, regionally and nationally rare, with only four known buildings surviving regionally; the other three are all related to the former Clark works. Following the First World War, the hall was extended and internally altered in the 'Art Deco' style. Subsequent addtions in the latter half of the 20th century created unsympathetic **additions**. The building is registerd as a Category A building in the District Plan, and is also on the New Zealand Heritage List as a Category 1 historic place, largely because of its technological construction and its historical context.

Figure 10: Warkworth Town Hall; past, present and possible future iterations

The hall was assessed by the former Rodney Council in 2005 for seismic performance and found to be earthquake prone. Following amalgamation it was subsequently closed in 2011 after structural issues where identified. Public consultation was undertaken to determine its fate. The process was not without contention, as not all members of the community were keen to retain the building. What came through strongly in the end, however, was a community desire to recognise its own bonds through its built heritage. As one online commentator stated:

> This building is a significant landmark in the area and provides a link to the past. Located close to the centre of town, the Town Hall is large enough to accommodate many important and varied activities. These include weddings, debutante balls, dances, movies, shearing competitions, children's ballet classes, musical events, and art exhibitions, to name but a few. All those who use this space have a sense of ownership and regard this historic building as a community icon. I believe that we need to restore the Town Hall to a functioning building again so that we can keep enjoying this valued part of our community. [D Gannaway 2012]

Ultimately it was decided to keep the hall, and Art Deco extension, which also has heritage significance. The later accretions are to be removed in a phased programme of work, with a new extension and remodelling of the upper floor to accommodate a lift and link to the new extension. The overall budget for the first phase of development, including the new build extension, was $3 million. The role of the Rodney Local Board was critical in securing funds for the first phase, and leading the support for fundraising to meet the targets for the future planned phases of work.

Figure 11: Non-fire rated Art deco interior alteration of main hall

The need to consider retention of original fabric was weighed against the seismic upgrade requirements. The nature of the glazed bricks – a key heritage feature, created some issues in terms of seismic upgrade options. In the end it was proposed that the interior Art Deco cladding, itself a non-fire rated material, could be replicated with a superior modern product. The removal of the cladding could then allow opportunity for internal strengthening to be applied, maintaining the original exterior appearance of the glazed brickwork. In this instance, the more significant, if less aesthetic, heritage fabric could remain visible.

3.5. Tools for seismically assessing buildings and estimating costs

Seismic assessments are performed in three generic stages as prescribed in the NZSEE assessment guidelines [17] – preliminary, initial seismic assessment (ISA), and detailed seismic assessment (DSA, which can be performed using a variety of methods). The initial evaluation procedure (IEP) is the method for ISAs preferred by most territorial authorities and is a provisional, qualitative screening procedure that provides an approximate assessment of seismic risk. In comparison, a detailed seismic assessment (DSA) typically provides more detail and involves calculations and/or computer models specific to the building being assessed. A “preliminary” assessment for purposes of this programme is effectively the IEP sans an assessment of critical structural weakness (CSWs, which are generally geometric irregularities). The procedure can be applied knowing only the building height, structural system, age of construction, and importance level [16].

As of mid-2014, over 500 seismic assessments had been performed on buildings owned by ACPD (including heritage as well as non-heritage buildings), including approximately 350 preliminary assessments, 160 IEPs, and 6 DSAs. Critical building characteristics needed for a risk assessment of the portfolio are summarised in Table 3. Floor areas were taken from representative buildings within each portfolio-risk group, and if not available from the service provider, were generally calculated as the footprint area measured from Auckland Council GIS multiplied by the number of storeys visible above grade. Extrapolated data intended to represent the entirety of each service portfolio was determined by taking the percentages of seismic risk groups for the buildings assessed within each service portfolio and applying them proportionally to those buildings that have not yet been assessed by any method.

Table 3: Summary of critical building attribute assumptions.

Service Portfolio -->	Corp-orate	Libra-ries	Comm-unity	Rec & Aquatic
Typical floor area of EQ-prone bldg. in portfolio (m^2)	900	570	500	5100
Typical floor area of EQ-risk bldg. in portfolio (m^2)	3000	720	700	4000
Importance Levels	2-4	2-3	2-3	2-3

Assumptions for preliminary cost estimates were based on a small number of case studies, as well as general proprietary knowledge provided to the technical leads at Auckland Council by local engineering consultants. Preliminary, empirical models for estimating the costs associated with commissioning detailed seismic assessments are shown in Figure 12. Note that these preliminary models do not account for differences in structural system, importance level, existing %NBS, target %NBS (desired after retrofit), or specific DSA methodology. Furthermore, ACPD expects that grouping buildings into packaged DSA projects may keep the cost of DSA per building lower than is indicated in Figure 12. DSAs are generally expected to be less expensive in Auckland/Hamilton than they are in Wellington, probably because of the higher design demands in Wellington and associated increased complexity of analysis and liability for the engineer.

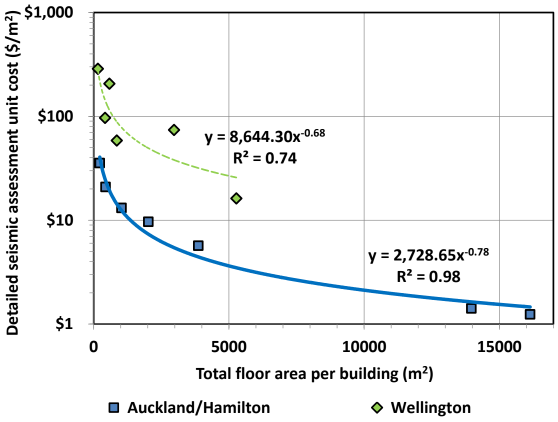

Figure 12: Preliminary, empirical models for estimating the cost to commission a detailed seismic assessment (DSA) in Auckland/Hamilton and in Wellington, respectively.

To date, seismic retrofit costs have been assumed to be approximately \$500/m^2 on average in order to upgrade buildings to 33%NBS and approximately \$600/m^2 on average in order to upgrade buildings to 67%NBS with variations accounting for existing %NBS and target %NBS considered. These values do not account for costs associated with non-seismic rehabilitation works, though such costs are being considered in ongoing efforts. The authors wish to emphasise the expectation of a very high variance in construction costs, and intend to control such variances as much as possible by packaging buildings of similar structural configurations and geographic locations together in future requests for proposal to engineers, architects, and contractors. Ongoing efforts to derive assessment and construction costs from recent seismic retrofit projects will lead to the development of more sophisticated models in the near future accounting for specific structural materials and systems, as well as other variables.

3.6. Responding to stakeholders

In a recent article on the earthquake strengthening of 217-221 Parnell Road (a ‘typical’ URM building of historic construction, though not listed or scheduled), a local newspaper, the *East and Bays Courier* captures some of the sentiment that Auckland Council recognises from its stakeholders.

> It's the building, with those bones, high ceilings, the beautiful leadlight windows. It's just part of that whole feel of something beautiful from a bygone era that can still be enjoyed in this time. A lot of my customers associate that with the shop. [8]

We see this almost daily at the planning coalface, as our heritage advisors and planners liaise with businesses, owners and tenants of commercial ‘historic’, or scheduled heritage buildings.

> This is affecting a lot of people. I've talked to people in Remuera, in the city, everywhere, in the same situation. [8]

The article describes the owner's concerns with the cost, but also their desire to absorb this and retain 217-221 Parnell typifies, 'the good steward'. Other examples relate not just to the cost of works, but effects on insurance premiums, to quote a reported example from Wellington:

> Simpson, like hundreds of other owners of properties that have been deemed earthquake-prone, finds himself caught in a financial pincer**.** He is trapped between the obligation to meet enormous insurance premium hikes while at the same time needing to save for the earthquake-strengthening work required on the old block of flats in which he lives. For Simpson being chairman of the body corporate at the 1928 Blythswood apartment building in central Wellington has begun to feel like a full-time ob. He says even before the Christchurch earthquakes, insurance cover for older buildings was drying up and premiums were slowly rising. But nothing prepared him and other owners of heritage apartments and buildings for the effect the Christchurch events would have on premiums. At Blythswood, building replacement insurance two years ago was $14,000 a year Last year it was $52,000. This year it is $132,000. [2]

Such stories have also been reported to the Heritage Unit in Auckland by building owners, prompting a proactive strategy to develop advice notes and liaise directly with insurance agents – but further work needs to be done here. The shift to 'sum insured' models also obscures the perceived cost in relation to insurance premiums, but for owners of heritage buildings finding an insurer can be a fraught process. In many cases the use of specialist chartered surveyors and insurance brokers, while incurring initial costs that owners are unused to paying, may result in long-term savings on premiums.

Others have also been caught by the interim response to the Canterbury Earthquakes. Five years ago, the Grade B scheduled Achilles House on Customs Street was upgraded, though not seismically. Responding to the government's proposed requirements for the Building Act, the owners are now seeking to retrofit seismic upgrades to the building, while seeking to maintain its tenants. In the main developers are meeting these costs themselves, but more support would be appreciated. In fact the authors are aware of only one specific grant for assisting earthquake strengthening that has been provided to the owner of a heritage building to date. This was for strengthening works to the Empire Hotel on Lorne Street, and was for less than $20,000. Other groups, in particular Churches whose assets are vulnerable but do not produce much in the way of economic return, are extremely concerned by such costs. This is requiring some hard decisions to be made around the retention of built assets.

3.6.1. The Auckland Council Seismic Steering group

In response to both the Canterbury Earthquakes Royal Commission of Inquiry report, and the proposed changes to the Building Act, Auckland Council formed a seismic steering group in 2013. The purpose of the group was to reflect key stakeholders within the Council Structure, who were able to identify and reach other internal departments, or to identify and liaise with external interests. The key areas of council represented by the Seismic Steering Group are:

- Property (ACPD);
- Building Control;
- Civil Defence and Emergency Management (CDEM);
- Community Facilities;
- Heritage;
- People and Capability Department;
- Communications; and
- Finance.

The role of the committee was to specifically consider an organisational response to the government's proposed amendments to the Building Act, and to make submission on behalf of the Council and the general community of Auckland. The importance of establishing such a group within an organisation of the size and complexity of the Council is clear. The role of the group is to continue to develop a policy response, and to consider the needs of its community and key stakeholders when providing internal advice to the organisation.

In the wake of the series of seismic events that struck Canterbury in 2010-2011, there has been a considerable increase in the perception of risk posed by earthquakes to communities across New Zealand. Particularly in places such as Auckland this has led to the need to communicate with building owners, tenants, the public, and other entities to balance the genuine needs for greater resilience with the practicalities and truths around such work.

For building owners there has been a lot of effort put in by council staff into providing points of contact and publishing guidance material to help them understand how buildings were being assessed, and what future action might need to be taken. Reassurance that the council is looking pragmatically at how legislative requirements can be actioned has been of particular importance following concerns that the whole process was being done without ground-truth understanding.

Another set of stakeholders that the Council has engaged with are insurance companies, banks, and their respective collective councils. Driven by financial considerations around the management of risk to, or posed by, older buildings their initial reluctance to provide lending finance or insurance on such structures led to valid concerns around loss of tenants and the crippling of businesses through this work. Auckland Council had an involvement in this regard by liaising with, sharing information, and discussing long-term plans with these entities. Many have become a lot more confident in working with owners to find appropriate solutions, rather than withdrawing their involvement and support.

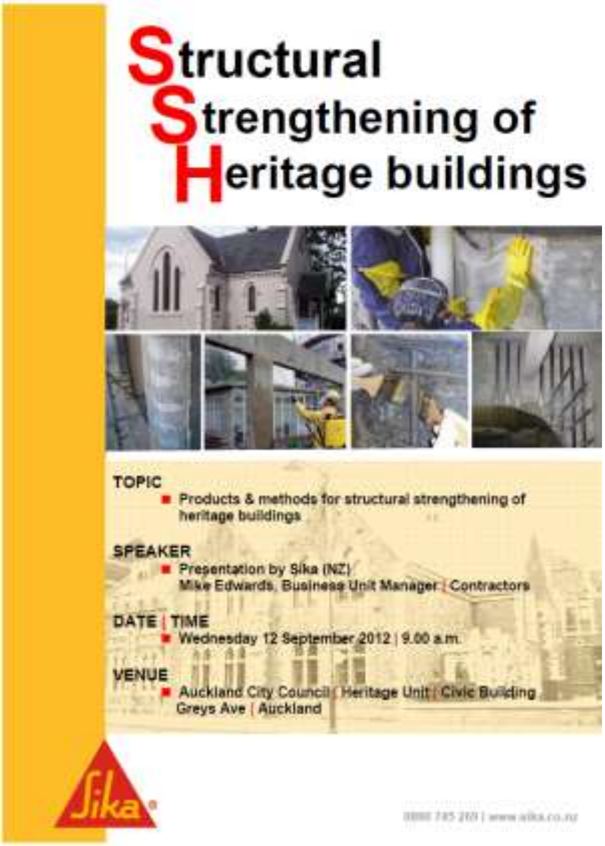

Figure 13: Example of practical advice to building owners - a seminar by contractors on earthquake strengthening techniques organised by Auckland Council Heritage Unit, 2012

3.7. Delivering Value

For the owners of 217-221 Parnell Road, there are business drivers, not the least of which is the cost on insurance, that determine their responses to the engineering risk of heritage buildings. But there are opportunities to explore here also. Costs are only economically unpalatable when there is no clear return on your investment to justify them. The Auckland Council as a property owner understands the problem of cost, but at least we have the ability to explain ours in terms of the long game, as custodians of the public benefit. We can demonstrate a social return on our investment, using the tools we have developed. In our experience, business owners often struggle to see this public good as justification, and perhaps fair enough – very often the 'status' of heritage is one not asked for by those who actually own and care for historic buildings.

We have explored the key areas of risk as experienced at Christchurch – poorly tied facades, unstable parapets. What is more, the failure of some of these elements can be triggered by factors that are non-seismic in nature, especially when combined with maintenance neglect. These things can be relatively cheap to retrofit, and to do it sensitively, but there is still a perception that there is no return on this investment. To the tenant, there may be increased safety from the risk of seismic event causing harm, but will they swallow the cost of increased rents to subsidise an owner, as for example at Achilles House? Where the owner is the occupier, there is no added value to be had here, except perhaps in reducing insurance premiums.

The local authority has potential to add value here. Systematic street upgrades might allow works to be undertaken, and also deliver a more inviting public realm, that in turn attracts new custom to commercial buildings. Flagship projects, such as the additions to Lopdell House and art gallery, or Shed 10, also signal intent by local government to invest in heritage buildings on part of the broader community, and can help to attract new investment. There is perhaps no clearer example in Auckland than the Britomart redevelopment programme, to highlight where a private-public partnership type approach can generate new economic and social interest, and create vibrant places.

Figure 14: Karangahape Road, Auckland. The Seismic Exemplar project combined with street upgrades might provide the opportunity to incentivise private owners of such buildings to upgrade.

4. Conclusions

Auckland Council recognises the responsibility to safety that needs to be respected when caring for our heritage buildings. It also needs to recognise that there are inherent tensions in the message it is required to send as a regulator, and the message it wants to send as an advocate. Very often we are met with the response from private owners that ‘Council’ is placing a double-burden on them – to retain historic buildings for public benefit, while requiring additional expenditure. In fact there are more complex drivers here, including the role of central government, the lending requirements of banks, the premiums required by insurance companies, and market forces in relation to property value. However, it is easy to label one or another party as the cause of woe, especially in the emotive space between the desire to retain our heritage, our livelihood, and yet to address the risk to life.

Sometimes, as regulators, where we can best assist our stakeholders, ratepayers and communities is to accept our role, and absorb some of the negative emotion that comes with it. We have a statutory function, and that is to ensure that property owners, including ourselves, reduce risk of fatal harm from seismic events and other environmental hazards. But on top of all this is the question “is this cost worth it?” This question needs to be answered carefully, thoughtfully, as leaders by example and with the best data that we can make available to assist other people to make an informed choice. Then, and as advocates, we can seek for an appropriate balance to reduce risk, and raise resilience.

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RESEARCH BEFORE RESTORATION

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Abstract
When presented with an item of historic interest we encounter a cumulative history of every event experienced by that object. Despite offering large areas for investigation, buildings are often severely compromised through neglect, functionality and fashion. Because of their size and complexity there is generally good opportunity to recover much information. Unfortunately inept restorative processes often destroy even more historic evidence and disturbingly when information is known often it is still ignored. Building codes and compliance can further frustrate sensitive restorative processes. The result is always a compromise.

Smaller objects, such as furniture, offer far more for flexibility for sensitive and appropriate treatment. Cost alone is far less a consideration and projects can be managed more intensely because of affordability, portability and size, but this is not always a virtue. Important heritage furniture is often severely compromised because it is small, can be very cheap and is unfortunately all too often historically misunderstood. In some cases a single object may survive to represent a period or genre. In New Zealand and Australia, countries with a relatively short (European) history, such a loss can leave a disproportionately large gap.

Research is vital to the understanding of any historic building or object. Critical observation can be extremely revealing. Mentally undressing later alterations or subsequent damage can then be compared with anecdotal, circumstantial and documented material to provide a very comprehensive, informed and layered picture. Only then should any physical interference be attempted.

All work should be as much as possible reversible and documented. It should not be apparent to the casual observer. All restorative work should mimic the intentions of the original creator/maker as far as possible, but still reflect the object's age. Non-invasive restoration using traditional materials and techniques leave later opportunity to recover more information and maintain harmony with the properties of old and introduced components.

A broad based observational approach can recover information to assist in heritage restoration. A sensitive restorative approach to match materials and traditional techniques for correct restitution of losses and offer long term stability will prevent future damage. Furthermore provenance will add value and interest to secure the wellbeing and safety of any historic artefact.

1. Introduction

The currency for forensic work at a molecular level may over-shadow more traditional observation. A fragment of material, for example a single board from an old building, may reveal a surprising amount of information. If we cumulatively add many such observations from one site or source, then we can get a surprisingly broad and layered picture. This new found information can be then compared to existing documented and anecdotal histories to further expand the picture.

Careful and thorough research of any historic object will provide the most secure approach which should precede any restorative work. Restoration is by nature invasive and there is always real potential for information to be lost and unnecessary damage to occur. Furthermore some intervention may be non-reversible and ostensibly a process designed for protection may be significantly compromise the project.

Sensitive and considered restoration should proceed when all information surrounding the object has been thoroughly analysed. For this process to succeed it is critical to understand and agree on the intended outcome <u>before work begins</u>. That is, work should commence to a clear destination in controlled stages.

Comprehensive research therefore provides a sound basis to underpin cautious and progressive work. It provides security for work to proceed along a predetermined path and offers confidence and certainty of outcome.

2. The Wooden Colonial House

By working backwards from a few fragments we are forced to consider deeply every detail. In 2012 an archaeologist asked me to remark on what I could determine from an old house's wall board [Figure 1]. In this situation I ask for no other information as I do not want my observations to be affected by 'prior knowledge'.

Figure 1: Reciprocating saw marks, c.1852.

2.1. Tui's Nest

I could tell that it was New Zealand native white pine or kahikatea because of the colour and extensive worm damage. This was a species used by the first European colonists before they realised its poor durability. Also, it is a species more often found at low altitudes, particularly in coastal regions, colder climates and in or near wetlands. In lower areas it sometimes predominated over more durable and attractive timbers. The saw marks, or kerfs, were most unusually from a reciprocating saw. These were rare in New Zealand, early and generally powered by water-wheel. There was one completely hand-made nail still in the short section of board. This type of nail is virtually never found in the colonial context and would not be found after the 1850s.

We have some good information. A species used by the earliest settlers, generally in the 1840s and a nail type that would also agree with that decade. There were saw marks that indicate an early and uncommon water powered saw, probably situated on a stream or river near the sea for transport, and a timber species possibly found in a coastal region typical of where first settlement occurred. The board in fact came from an historic cottage, "Tui's Nest", in Port Lyttelton. [Figure 2]. The house, built about 1853, was owned by John Parsons who captained immigrant ships to Otago and Canterbury after 1848. Totara and kahikatea were the two dominant species on Banks Peninsula and John Pavitt had established a reciprocating saw mill around 1852 in nearby Robinsons Bay. Tui's Nest was demolished in 2012.

Figure 2: Tui's Nest, Lyttelton, c.1853.

2.2. Pavitt Cottage

A survey of the second surviving Pavitt Cottage [Figure 3] indicated a change of saw type. The first reciprocating mill had burnt down about 1854 and a new circular saw mill was subsequently built. The oldest front part to Pavitt's house showed all framing was of low-grade circular-sawn totara or kahikatea, consistent with it having been built after the completion of the second mill. This was extremely helpful in dating Pavitt's house since no surviving records indicated when the property was built. Further investigation showed that all timber had been hand dressed and moulded with traditional profiled planes [Figures 4].The later rear wing, built in 1865, had machine profiled tongue and groove wall linings. This gave an end date to when the building must have been completed.

Figure 3: Pavitt Cottage showing older front part built c.1856-8 and newer rear wing from 1865.

Figure 4.1: Kahikatea circular sawn board with hand planed tongue.

Figure 4.2: Same board as in Figure.4.1 showing reverse side hand planed. The tear lines show that this was done while the wood was still wet soon after felling.

2.2.1. Nails

I will discuss nails and screws to detail how such seemingly minor artefacts can be so revealing. All nail types at the Pavitt site were the Welsh

'Ewebank' sliced and stamped or sheet cut pattern, but none were found to have that maker's characteristic post-1869 star impressed on the head. [Figure 5].Two head patterns were noted to the largest 3 inch or 75 mm nails. One removed from the interior of the front (older part) downstairs bedroom cupboard had an irregular faceted head, consistent with the earliest Ewebank nail pattern. Historian Chris Howe has surveyed early Australian buildings and notes:

> These nails appear to conform to the Cordes-Slocum patent of 1834 for their wrought iron nails. This is the earliest 'Ewebank' pattern from the J. J. Cordes & Co of the Dos Works, Newport, Monmouthshire factory and examples have been found to have arrived in Australia by 1837 [1].

Figure 5: Ewebank nails from 1865 rear wing (top) and older c.1856-8 front bedroom (bottom).

The sample nail had (machine) ejection finger marks to the upper shaft below the head while the shaft middle had the typical Ewebank bulge. The head had compression fractures indicating it may not have been red hot and lost some plasticity while being forged. Most importantly it had raised ridges to top and bottom edges of its parallel sides, caused by eccentric rollers on the 'patented' milling machine squeezing and elongating the nail rod into a new cross-sectional form.

The second nail retrieved was found in the attic part of the newer wing and had consequently degraded more because of damp. There was an unidentified 'Dot X Dot' impression to its head and it had a regular four sided tapering shaft. Another development of Henry Ewebank's was a machine with converging rollers to draw out the nail and taper it to a point. There were clear impressions of machine stamping to form the nail head observed from the folded metal under the nail head. They were on diagonally opposite 'corners' of the nail shaft suggesting two <> shaped vice heads gripping the nail as the head was hammer formed in a mould. Howe has noted that 1850s buildings in western Victoria, Australia, feature several types of nails cut from pre-profiled sheets. The nail shanks were cut from across the shaped sheet and then separately headed, consistent with a later Cordes & Co patent. Pavitt Cottage appeared also to have this pattern.

2.2.2. Nineteenth Century Screws

Four original screws removed from a 'japanned' cast butt door hinge were Sloan/Nettlefold patterns, manufactured prior to 1858. [Figure 6]. Two screws had blunt tips, non-tapering shafts and deeply cut, very sharp threads when compared to the other two shorter (later but still original) screws. The two types were made quite differently, most significantly in the way the thread was formed. The blunt tipped screws had their threads cut on a die which was wound onto the blank screw rod, rotated to cut the thread. This is quite evident where the metal has been pushed sideways by the cutter's pressure to create a double lip to the initial thread. Joseph Whitworth patented his un-locking clasping nut for forming threads in 1839. The advantage was that it did not need rewinding back down the threaded screw shaft. Its use was commonplace when he displayed it at the 1851 Great Exhibition.

Figure 6: 1854-8 pattern screws (left) 1839-54 pattern (right).

This 'blunt' screw pattern is typically English and can be found in New Zealand furniture until the middle to late 1850's [2]. The metal on all four screws has been squashed while hot, causing the thread to rise beyond the original extruded rod blank diameter. In 1847 New Yorker Thomas Sloan patented his machine for forming pointed screws and in 1854 Englishman John Nettlefold bought the rights to manufacture those screws from Sloan's invention. By 1858 this machine was further improved to fully taper the screw to the more familiar conical shape. The pattern of the two 'pointed' screws followed the American model. Their counter-sunk heads were angled steeper and the slots wider. Interestingly they had a rounder outer flange as though they were not entirely tool cut on a lathe but possibly stamped. No chuck or grip marks were seen on any screw upper shaft perhaps implying more automation. The important point to note is that those two screws tapered to a point quickly rather than the 'slow' progressive taper of slightly later made screws. These are in fact the first totally machine formed pointed pattern screws. It is clear that both screw types (blunt and pointed) were available during the construction of the initial stages of Pavitt Cottage. The screws identified for this study from the older part of Pavitt Cottage were all manufactured before 1858.

From small clues such as the use of certain tools and manufacture dates of hardware we have been able to narrow the date of the Pavitt Cottage construction. Other evidence not discussed here established a reasonably precise date of 1856–58.

3. Banksia - Original Furniture

'Banksia' a nearby Akaroa property built in 1860 bore direct comparison in style and materials. Both houses were originally quite modest, consistent with early colonial architecture; variations of a five room plan, containing three bedrooms, a living room and kitchen, with additions some ten to twenty years later. Until 2011 Banksia had retained some original imported and colonial made contents. A quick survey was able to broaden our understanding of relevant period fashions and manufacturing processes. Furthermore these could also be found in the fabric of the building. Everything related, which perhaps should not be surprising, providing reassurance that good comparative information can be found circumstantially.

Two cabinets could be highlighted [Figure 7.1 and 7.2]. A neo-classically inspired chiffonier of hand planed circular sawn totara planks stylistically mimicked the fire surround of the same timber. Both were almost certainly made by the same local cabinetmaker. A simple homemade plate rack dresser in figured totara was likely made from off-cuts when Banksia was first constructed as timber, tool marks and nail types all matched. The crude construction was below that of a cabinetmaker and more in line with a carpenters skills and familiarity with wood.

Figure 7.1: A classically inspired hand planed totara chiffonier with materials and architectural features original to Banksia, 1860.

Figure 7.2: Primitive circular sawn totara dresser, original to Banksia, likely made c.1860+ from off-cut material after the construction of the house. It would not be possible to associate these two pieces on style. It was done through use of identical materials and a common history at the same property.

3.1. Further Timber Analysis

With timber we can also look at dendrochronology, that is, the width between annular growth rings to determine when a tree was milled. The end grain of a board will exhibit variations of width in the rings which will correspond exactly to local climatic conditions as the tree was growing. This natural 'bar-coding' can be matched to known historic weather patterns. The rings are narrower in colder years. It is the sap-wood area, particularly in centre to edge cut quarter sawn boards that will be most revealing as the tree adds layers in circumference each year. The last ring to the outside of the tree will determine the year it was felled, even the summer or winter season is sometimes possible to predict. This process has been successfully used to date the oldest wooden building in North America, Fairbanks House, precisely to 1641 and is common practice for dating paintings on wood panels and stretched canvases. Furthermore timber samples can be taken to determine the chemical composition of the wood. The identical species growing in different soil types will take up different proportions of minerals which can be plotted against the composition of known regional soil types. Typically this is a destructive process as analysis is done from ash [3].

3.2. Colonial Furniture

The relative simplicity and size of furniture does focus investigative attention to small details and critical scrutiny. This discipline can be transferred to larger structures such as buildings which present expansive areas for investigation. Furniture interpretation and restoration offers some advantages by comparison to buildings; primarily because of size, portability, project manageability, and significantly, economy. Equally it does come with notable challenges. Furniture size restricts the potential for research material to be recovered and is often frustratingly exacerbated by severe modification. Further, rare and important objects are frequently misunderstood because few clues remain to indicate their origins or historic context. Generally all information must be gleaned from the object itself. Sometimes only one discovered example may survive to represent a particular genre.

3.3. Researching Extant Historic Furniture

Very careful observation cannot be overstated as the single most important aid to recovering information. This should be done before comparison to existing provenance or anecdotal material. Initial impressions should be recorded within a few minutes as they will quickly fade with familiarity. The perpetrator of any alterations will rely on an overall first impression to convince the observer of authenticity. Invariably this will not be supported by detailed inspection, particularly of hidden ‘dry’ surfaces such as backs, interiors and bottom boards.

Later ‘improvements’ or modernisation would have been undertaken for several obvious and explainable reasons while natural degradation can largely be accounted for by poor construction, low-grade materials and neglect. Motivations for these are generally:

- Economic gain or to add value.
- Fashion and style changes.
- Change of use and need.
- Degradation due to breakage or decay.

The first two points should be regarded with suspicion as generally there will be some attempt to disguise any modifications. It is extremely difficult to successfully achieve either point’s outcome and evidence usually abounds, although at first glance not always apparent. Typically there will be fresh cuts and timber will be left with partially oxidized surfaces where it has been reshaped. Likely there will be heavy use of introduced colour, incorrect tool marks, modern adhesives (that is non-gelatine), later nail/screw types, inconsistent decorative adornments or out of period details. The existence of one later component or evidence of interference is enough to indicate compromised authenticity and certainly should arouse suspicion. If even one original nail or screw can be found then all others can generally be discounted and timeframes can be significantly narrowed for corroborating period features.

The latter two points usually occur for more obvious reasons, but unfortunately often result in larger original material loss. Modification is generally self-evident where an object has been altered to perform a different use. An example might be a pedestal sideboard where the back has been removed and converted into a bed head board and the pedestals made into bedside cabinets. Generally little attempt is made to hide the origins of the remodelled furniture as the process is mostly one of partial deconstruction.

The reverse happens less frequently where a modest item is embellished or incorporated into another piece. To achieve reasonable success it involves higher levels of cabinetmaking skill and knowledge of period style. The trade term ‘marriage’ is where two unassociated pieces are combined. A common example would be a glazed bookcase top fitted to a chiffonier or secretaire base of vaguely similar timber and age. Any inconsistency of cabinetmaking style, such as joint formation, edge mouldings or even screw or nail types, will reveal such combinations. Honest repairs can be viewed and explained as such, despite almost invariably being of poor competency.

Moving components, such as doors and drawers, are particularly prone to user damage. Distortions in timber such as severe cupping and splitting again are understandably subject to sometimes crude remediation. Woodworm infestation frequently and unnecessarily results in the replacement of large areas of secondary timber, such as backboards and framing, with the consequential loss of much original and informative material. It is more serious than might be imagined. Although the higher quality front ‘show-wood’ may have been refinished more than once in the life of a piece of period furniture, the loss of original and untouched bottom and back boards removes all hand tool marks and securing nails which may have been the only remaining indicators of the objects true age and origins. Expensive imported timbers can be used in ‘seen’ surfaces but cheaper indigenous woods are always used for basic construction. Strangely they provide most useful information.

Subsequent interference can be ‘undressed’ and discounted as non-original once the perpetrator’s motivation is explained. Initially this is purely academic but ultimately will happen in practice. This is vital to begin the process of gathering information prior to restoration. As previously discussed with the house examples tool marks, both hand and mechanical, timber types and hardware should be compared to known dates of popular use. Laziness should never be ignored! No cabinetmaker would hand saw wood when a machine was available. Each wooden component, sides, tops, backs, rails, feet, bases, mouldings, should be noted for originality and their relationship with mating elements. All dry surfaces should appear consistent in colour and texture as should a logical use of primary and secondary timbers. Modern synthetic adhesives developed after the 1930s should not be present with only traditional animal based gelatine, glue evident.

Figure 8: This c.1830 mahogany chest is possibly the oldest New Zealand made example. It was identified from its rimu and tawa drawer linings. Period design, pit-saw marks, nail types and pre-1839 screws with hand forged locks aided in dating and location of manufacture.

Occasionally supporting information is found from another piece of furniture by the same craftsman with a distinct woodworking signature just as reference can be made to historic cottages in a similar location. The portable nature of furniture does mean most often that this context is lost. Some timber species were more popular in specific regions, for example cedar exported from New South Wales to Dunedin, black wood in Western Australian, Huon pine in Tasmania, kauri in as the primary show-wood in Auckland but totara and rimu in central and southern New Zealand. Hardware specific to certain English, usually Birmingham, manufacturers and foundries was often imported by a single colonial agent. Handle patterns, lock and hinge types display regional variations depending through which port they were originally shipped. Nineteenth century newspaper accounts of new stock arrivals and advertisements can be remarkably detailed and word recognition software makes searching now fascinatingly easy [4].

Figure 9: Restored rimu and kauri chest c.1838-9 made by Northland cabinetmaker and missionary William White. Identified by timber species, saw marks, screw & nail types, knob patterns, neo-Grecian style and provenance.

Patterns by major nineteenth century designers, cabinetmaking enterprises and large retailers both in Britain and Australasia offer excellent supporting documentation. Attempts to modernise antique colonial furniture typically focus on the removal of decorative features identifying an object with a past style. Furniture follows proscribed fashions and while there are a myriad of design variables they conform to identifiable patterns which can prove invaluable for the accurate recreation of lost decorative features such as carvings, mouldings, veneers, turnings, handles and surface colour treatment. An individual cabinetmaker's style can be mimicked, be it clumsy or accomplished, to replicate lost ornamentation.

New research has proven identical designs were used across the colonial world during the same periods [5]. Patterns were no more than simple line drawings, while fine detail was usually left to individual craftsmen's personal taste or his client's whims. Intensive hand produced decoration added cost and furniture designs were almost invariably modified. Additionally several patterns may have been blended together for individuality so the original inspiration may be obscured. Cabinetmaking had agreed rules of construction controlled by the unique properties, notably the directional grain restrictions, of wood. This demanded certain joints be formed with regard to expansion and contraction, longitudinal strength and lateral weakness. The peculiarities of timber were trade knowledge understood by any apprenticed cabinetmaker. In other words, a good current knowledge of cabinetmaking will fill in a lot of gaps.

4. Restoration

In some circles restoration is considered extreme. Conservation is much the preferred choice where an object is protected in an inert and stable state with no radical intervention. This does however deny severely damaged items opportunity to be displayed or viewed as they once were when first created. The morality of careful restoration therefore needs to be appreciated and very strict guidelines must be put in place.

Restoration is an honest and informed effort to reinstate an object back to its original state as nearly as possible.

- During the process no original material should be removed or lost.
- Where practicable all work should be reversible.
- As far as reasonable only materials and tools available to the original creator/maker should be utilized to provide interactive and visual harmony.
- No effort should be made to reconstruct an artefact beyond the talents and resources of the original creator/maker or what the accumulated evidence suggests.
- There should little or no evidence of restoration. All work and observations should be documented.

Restoration is a complex subject, but if these five principles are adhered to then it very much narrows the options available and aids decision making.

In short, it should appear as though no recent work has been undertaken and that history has been kinder to the object than was in fact the case. It is simply putting back the history. Work should be done to ensure the long term preservation of the item; to add strength and durability, to add interest, add value and aesthetic appeal. To give an artefact status will protect it from future interference and intervention.

5. Conclusion

When faced with even minimal original material we are forced to tease out every clue to recover usable facts. The important message is that careful observation and research can recover significant historic data. Understanding the way constructional materials have been modified and worked provides a layered view of the past. For example, the availability of timber species and how they have been processed is very telling. All man-made components carry the evidence of their manufacture and those processes are often well researched. Even a single nail carries a surprising amount of information while backgrounding equally esoteric perspectives, such as fashion or altered need may add additional clarity to support previous observations. This can then be cross-referenced against archival research and provenance. If multiple histories are collated then timelines can be graphed, locations plotted, various motivations, crafts and styles recognised to allow restoration with integrity to cautiously proceed.

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ENGINEERING HERITAGE AND NATURE, FINDING A BALANCE: AN AUCKLAND PERSPECTIVE ON THE EFFECTS OF NATURAL HAZARDS ON COASTAL AND MARINE HERITAGE

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Abstract
Auckland's engineering heritage, while perhaps perceived as mainly European/colonial, embraces evidence of several hundred years of Māori occupation of Tāmaki Makarau, principally in the form of terraced volcanic cones and agricultural areas. Overall the wider Auckland coastal vulnerability includes lower level Māori sites, together with foreshore protection works and heritage buildings, not least their contents.

The engineering heritage is vulnerable to a number of natural hazards. Earthquake risk may be somewhat less than further south, but the city lies on a narrow isthmus between two large harbours and on a volcanic field which last erupted a mere six to seven hundred years ago. Tsunami risk is significant for the eastern coasts, whether from far-field trans-Pacific events or more seriously from near field movements on the Hikurangi subduction zone or the Kermadec trench running into the Bay of Plenty.

This paper highlights specific examples of impacts of volcanic eruption and then discusses heritage vulnerability to earthquake, tsunami and extreme climate-related events. Reference is made to much ongoing work by Auckland Council and supporting agencies, not only in seismic strengthening of heritage buildings as covered by other papers, but updating of potential coastal hazards from tsunami and increasing high sea levels and appropriate responses.

1. Introduction

Engineering heritage, commonly perceived as coming initially from the colonial era, had a late start in Auckland compared with main cities further south. It was the capital city shortly after the Treaty of Waitangi signing in 1840 until that moved to Wellington in 1865. Early developments centred around the port and preoccupation with the land wars and subsequent expansion southward into the Waikato. City development only really started from the 1870s.

But Auckland's engineering heritage in broad terms goes back long before European arrivals in the 19th century. This paper's scope starts 700 years ago, discussing remnant evidence of Māori occupation to give an overview, in coastal terms, of the balance or lack of it between engineering, heritage and nature.

Heritage features along Auckland's coasts are especially vulnerable to natural hazards. The city sits on a narrow isthmus between two large harbours, itself studded with volcanic cones. While earthquake hazard is relatively low, tsunami risk is becoming more clearly defined. Oceanic storms are frequent, particularly with relevance to the more populated and historically developed eastern coasts

The city was one of the last developed in the former British Empire but became the key port in New Zealand's colonial era and several heritage features may be at risk. In some cases it may not be the structure itself as much as the treasures it contains.

In heritage terms little remains of the early waterfront work (in contrast with the 1837 stone wharf at Whitianga). However sufficient port buildings from the turn of the 20th century remain to demonstrate the port development and substantial 'reclamation' (i.e. filling in the harbour).

2. Māori Heritage in Tāmaki

Sometime in the 13th century a group of East Polynesian explorers and colonists arrived in Aotearoa/New Zealand. On their double hulled sailing waka they transported their families, tools, animals and plants. They found the largest landmass to be settled by Polynesians, a land teeming with birds and seafood, but unlike their tropical homelands it was a temperate place. Skills developed for life in the tropics needed to be modified and to assist this process anywhere that was warmer, or could be made warmer, was particularly favoured and valuable.

Auckland, or Tāmaki Makaurau, was one of those places. With two large harbours, more than forty pocket sized volcanic cones and thousands of hectares of volcanic soil, it was an ideal place to live.

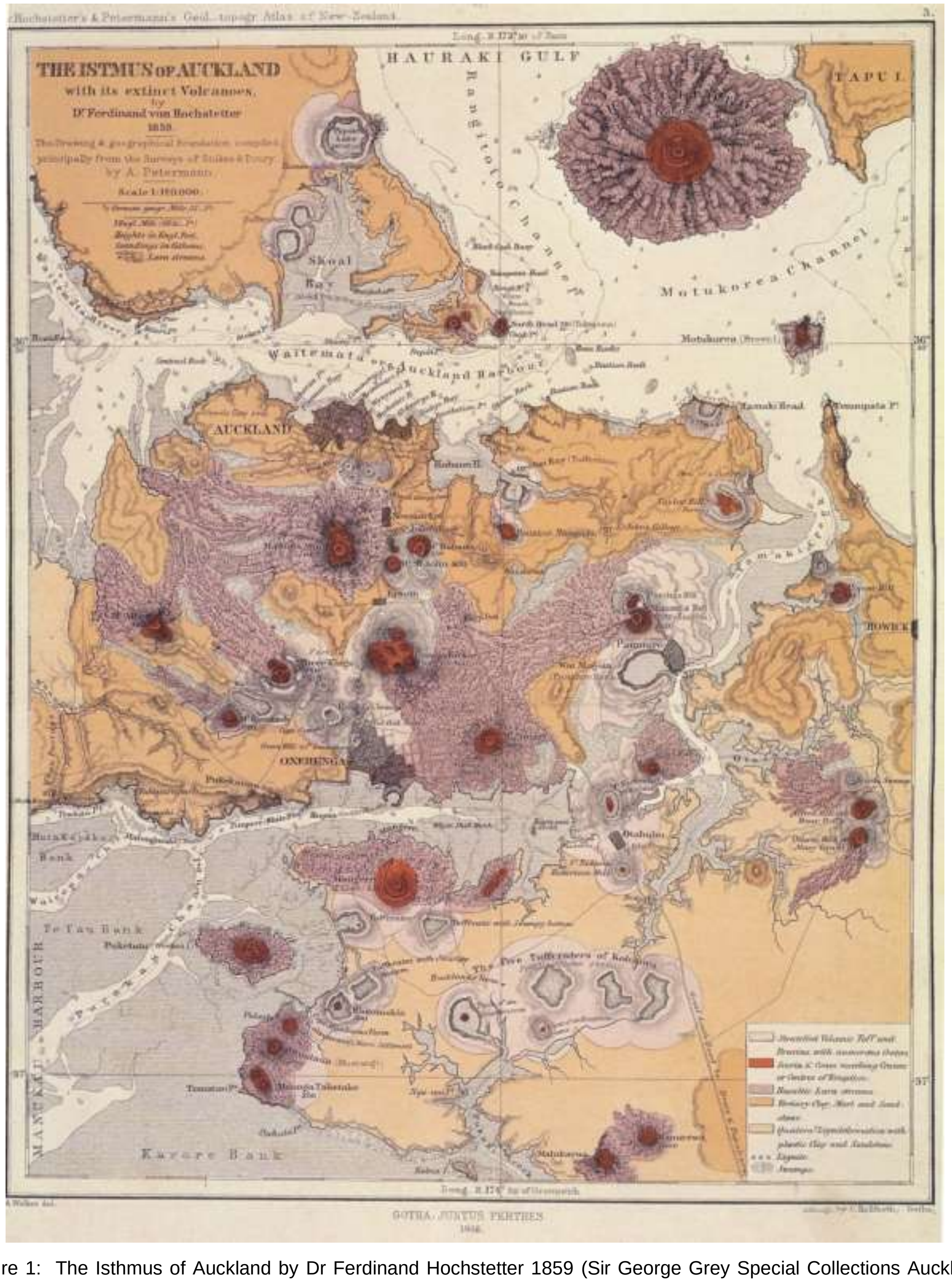

Figure 1: The Isthmus of Auckland by Dr Ferdinand Hochstetter 1859 (Sir George Grey Special Collections Auckland Libraries NZ Map 5694b).

The free draining volcanic soil was much warmer than the neighbouring clay soils and more suitable for the crops brought from the tropics. By using the rubble found in the volcanic areas to build solar heated garden nursery beds and with the development of new storage methods, the rua or kumara pit, the Māori population expanded rapidly covering most of the volcanic parts of Tāmaki.

With population growth came competition for garden land. By the 16th century Māori started to fortify settlements to defend both households and food storage areas. Headlands were defended by deep ditch and banks and the volcanic cones terraced and palisaded to create secure places to live. The evidence of these substantial earthworks is still clearly visible on the larger volcanic cones.

Figure 2: Mangere Mountain Pā, a painting by Chris Gaskin (Courtesy Department of Conservation).

In Tāmaki this lifestyle continued until the late 18th century when warfare and the arrival of muskets led to depopulation and the abandoning of many of these old pā and gardens. When Pākehā (non-Māori immigrants) arrived increasingly from 1840, they found an area described as 'a sea of fern.' Under the fern were the remains of hundreds of kāinga (villages), pā and gardens. This huge archaeological landscape was gradually eroded by the new city. Roads, houses and other services were built across the old field systems and the volcanic pā, and a rich rock resource started to be quarried. Until recently there has been little balance between development and heritage protection. Of the thousands of hectares of volcanic fields with their Māori garden walls and stone structures less than 200 hectares remain. Many of the cone pā have been quarried away, Mt Cambria (Takaroro) in Devonport, and Otuataua, Mt Smart (Rarotonga) and Elletts Mountain (Maungataketake) south of the city, have completely disappeared and many others so damaged as to be unrecognisable. Several of the larger cones have been flattened to accommodate water reservoirs and the access to them.

Today the remaining volcanic cones and two major remaining areas of volcanic fields have been protected and while damage from human activity still occurs, it usually by accident rather than design. Some sort of balance has been reached but for most of these extraordinary features it is too little too late. From this year, katiakitanga (guardianship) of several major cones is being vested in local hapū or iwi (descendent groups and tribes).

As well as the settlement in volcanic areas, the other main concentration of Māori settlement in Tāmaki was coastal. Kāinga and pā were often built on headlands or beach-fronts. These sites are facing another threat; often this is due to cliff regression of erodible Waitemata series sandstone, or beach erosion, sometimes by sand or gravel extraction.

3. A Unique Volcanic Memory

One of New Zealand's most important archaeological sites is on Motutapu Island in Auckland's Hauraki Gulf. Around six hundred years ago the last phase of Auckland's largest volcano, Rangitoto, erupting a few kilometres away, progressively covered a village. After the initial eruption, a group accompanied by dogs left clear footprints in wet volcanic material which over time solidified.

Figure 3: Rangitoto Eruption (Courtesy Department of Conservation).

Since the 1960s pieces of these footprints have been eroding out of the beachfront, and since 1980 numerous attempts have been made to protect the ancient buried village, initially using timber and rubble sea walls, both of which did little to protect the site and may have exacerbated the problem.

Figure 4: Sunde Site Motutapu Island (Courtesy Department of Conservation).

It was initially unclear why this particular beach was eroding until some historical research indicated that scows, the flat bottomed early colonial sailing barges had collected gravel and sand for Auckland building projects. The solution to the exposure of this important site was 'beach replenishment'. The profile in front of the old village has remained at a higher level and while not giving 100% protection is working better than engineered solutions like breakwaters or walls.

4. Earthquakes and Volcanic Eruptions

Auckland is generally perceived as having relatively low seismic risk compared with other parts of New Zealand. The last significant earthquake was in 1891 on the Waikato fault some 50 kilometres south of Auckland. Occasional minor tremors remind us we live on a volcanic field, at least two noticeable within the last few years and some 80 tremors since 1996 [1]

A recent overview of large scale faulting in the Auckland region [1] highlights the Wairoa fault as the most potentially active, but concludes that a greater risk may be from unknown faults buried under volcanic or other more recent material

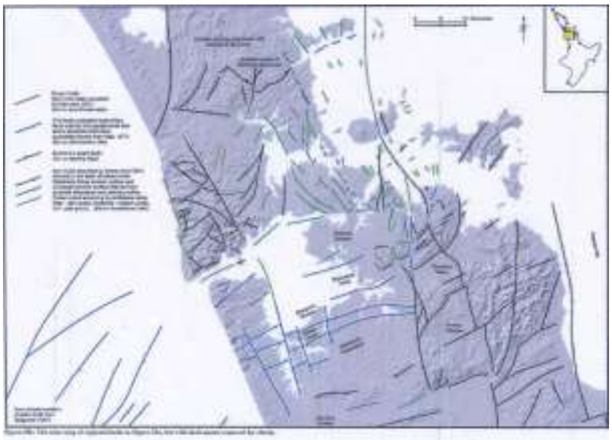

Figure 5: Faults previously recognised in the Auckland Region (Reference 1 Fig. 20b Page 40).

Extensive seismic strengthening has been applied to numbers of large heritage buildings in the city as described in other papers. Coastal structures vulnerable to seismic damage would include historic defensive forts dating from the late 19th century (the era of Russian invasion fears), mainly on the crest of North Shore cliffs and volcanic cones.

The Māori prehistory and its vulnerability has already been discussed, the major losses being occasioned by colonial settlement rather than nature. It has been noted that early Māori witnessed the last volcanic eruption – it was that recent! However there can be no prediction of future frequency, only to assume the volcanic field is not dead. The Auckland War Memorial Museum currently has a display which graphically demonstrates the effects of a new volcano erupting in the Rangitoto channel, coincidentally near the inferred site of the 2011 tremor.

In the event of an eruption, the effects on heritage items would be the least of Auckland's concerns.

5. Tsunami

Recent and ongoing research by crown research institutes, NIWA (National Institute of Water and Atmospheric Research Ltd) and GNS Science (Institute of Geological and Nuclear Sciences Limited), is defining in broad terms the risk to lower lying areas of the North Island's east coast. The East Cape and Bay of Plenty coasts are most vulnerable to near and far source tsunami, with greatest risks from undersea earthquakes on the tectonic boundary between Pacific and Australasian plates, as manifested by the Hikurangi and Kermadec subduction zones

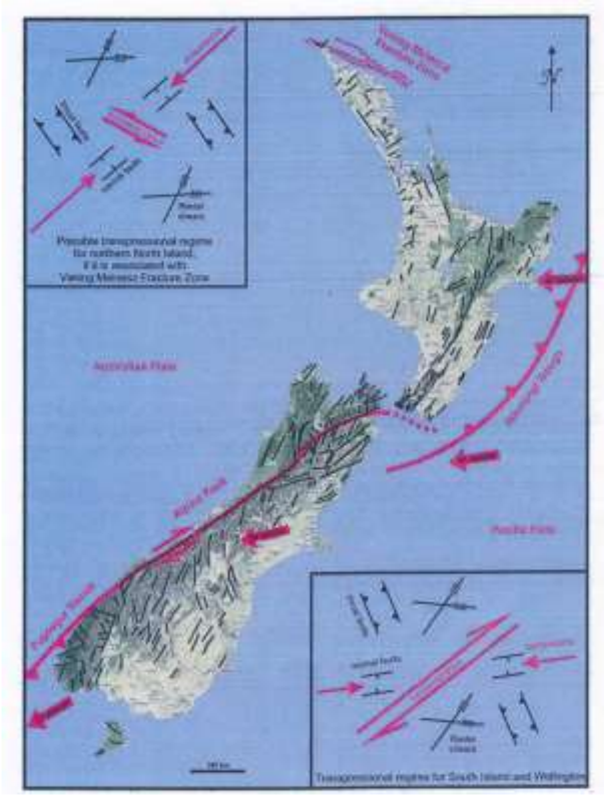

Figure 6: Hikurangi Trench and main fault lines (Reference 1 Fig32 Page 62).

There will be less than one hour's warning for Bay of Plenty communities from the latter and evacuation procedures are receiving priority from Civil Defence Emergency Management.

In Auckland, heritage items at risk would include the several kilometres of basalt rock sea walls along Tamaki Drive and shorter lengths in Devonport. As with the Lyttelton graving dock in 1960, there could be over-topping and damage to the historic Calliope dock in the Devonport Naval Base.

With regard to the historic stone house at Mission Bay, the new Naval Museum in Torpedo Bay under Devonport's North Head, Mansion House at Kawau Island and even earlier historical buildings in the Bay of Islands, (Paihia, Russell and Kerikeri) the heritage items most at risk could be the taonga (treasures), art works and artefacts in the buildings. Consideration should be given to their security or removal in the event of ground floor flooding, if not structural damage.

The range of physical tsunami hazard is becoming more evident. Smaller harbours like Whitianga and Tutukaka have experienced severe and repeated tidal flows and surges in sympathy with tsunami wave periods, usually over more than the twelve hour tidal period and hence coincident with at least one high tide. Larger harbours like the Waitemata did not respond to events like the Samoan earthquake tsunami other than with small fluctuations *(pers. com).*

The following comments are summarised from the Executive Summary of the Ministry of Civil Defence and Emergency Management's 2013 Review of Tsunami Hazard in New Zealand [2]

- New research and improved modelling shows hazards on the North Island east coasts are higher than previously estimated.
- New Zealand has experienced about ten tsunami of five metres or more since 1840.
- The report draws on lessons from the 2011 Tohoku tsunami in Japan which indicated non uniformity in ruptures between tectonic plates.

The possible effects from near field events on Auckland's east coast have been modelled and likely areas of inundation shown on publically available maps.

Figure 7: Tsunami Evacuation Zones for Devonport. Shore exclusion zone in red, evacuation zone in orange and yellow (Ministry of Civil Defence Reference 2).

Warning signs are displayed on popular beaches, and evacuation warning are being set up by telephone and siren. Tsunami responses are part of training of local emergency response groups. Auckland Council is developing data portfolios to enable local board and community response groups to inform property owners, including those of heritage items, about managing their individual risk.

As regards the Ports of Auckland, the principle heritage features at risk could be the National Maritime Museum at Hobson Wharf and its associated vessels. Experience from smaller harbours shows that very high ebb velocities can cause instability to moored displacement vessels followed by elevated water levels breaking moorings. Clearly the results and effects would be greatly magnified in the commercial port, and in Auckland's numerous yacht marinas. Of note is only a very few vessels of all sizes put out into the harbour when advised of the Samoan earthquake (*pers. com).* In that event there were no noticeable tidal movements compared with excessive and repeated variations in Tutukaka, Whitianga and other smaller harbours.

It can be noted that the 1960 Chilean earthquake tsunami exposed the bones of the 1840 wreck of the *HMS Buffalo* at Whitanga. Given the relevance of the ship to the citizens of Glenelg, South Australia, there have been short-lived suggestions of salvage of at least some parts of the wreck.

6. Coastal Inundation by Storm Tides and Waves in the Auckland Region

The above is the title of a NIWA report prepared in 2013 for Auckland Council [3]. The study calculated extreme sea level elevations for a range of annual exceedance probabilities. The three main harbours considered were Waitemata, Manukau and Kaipara. The Waitemata and its adjacent coast have the most heritage significance. The effects at high tide could be similar to those from tsunami. This has been experienced in recent months and is likely to become even more frequent with rising sea levels and climate change. Sea level rise at Auckland has been measured at 150 millimetres (mm) over the past 100 years, with variations mainly in sync with El Niño Southern Oscillation shifts.

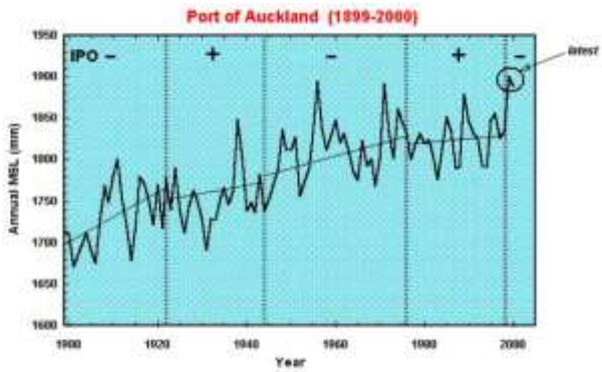

Figure 8: Annual mean sea level at Port of Auckland since 1899. The overall trend has been 1.4 mm rise per year, (http://www.niwa.co.nz/publications/wa/vol9-no4-december-2001/sea-level-on-the-move).

The heritage wall along Tamaki Drive was unexpectedly over-topped with some damage by a short lived storm surge at high spring tide in June 2014, with water flowing towards both Mission Bay and Kohimarama. Mission Bay beach head was over-topped too. However no adverse effects were reported at the Mission House.

Figure 9: Flooding of the North western motorway during the 23 January 2011 storm-tide (http://blog.metservice.com/tag/wind/page/2/).

The NIWA study produced inundation maps rationalising results of earlier studies, together with allowance for sea level rise scenarios of +1 and +2 metres above present day mean sea levels.

Less evident, but still historically significant, are the World War II pill boxes around the entrances to the Waitemata Harbour. Some of these low profile structures are vulnerable to the regression of sandstone cliffs from wind and wave erosion, possibly exacerbated by sea level rise.

Oldest of all examples of natural and human impacts on geological heritage are the threats to the so-called buried forest north of Takapuna on the North Shore. Basalt flows from the Pupuke explosion crater enveloped a standing forest leaving casts of the fallen trees. The largest of a standing kauri is threatened by removal of erodible tuff from under the basalt due to earlier quarrying and resultant exposure to wave action. Concrete underpinning has afforded at least short term support to a unique tree cast in which the bark plates are clearly visible (Brett Avenue, Takapuna).

7. Conclusion

Auckland's heritage at risk from natural hazards may not be extensive geographically, but the time spans involved, covering geological history, Māori occupation and European colonisation, merit detailed knowledge of such treasures and allowance for their protection or at least full documentation. Most at risk in some historical buildings may be the taonga and artefacts on display if not properly secured or elevated in the event of buildings being flooded.

8. Acknowledgements

The authors would like to acknowledge the assistance of Richard Woods of Auckland Council and John and Sue La Roche for the editing of this paper.

9. References

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HERITAGE BUILDINGS - SEISMIC RISK MANAGEMENT, A STRUCTURAL ENGINEER'S PERSPECTIVE

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Abstract
The recent earthquakes in New Zealand have highlighted the vulnerability and risk to life safety of some of the existing building stock across the country. Many of the most vulnerable buildings are heritage buildings. It is important for New Zealand to satisfactorily address risk to life safety from earthquakes whilst achieving measure of heritage preservation.

This paper first discusses the issues and the risks associated with earthquakes and high risk buildings, along with the proposed changes to the regulatory regime for earthquake prone buildings.

A staged seismic risk reduction strategy aimed at progressively improving the seismic performance and resilience of the highest risk buildings is presented. This involves aligning a set of performance objectives with various stages of seismic strengthening, available funding and a client's objectives, including heritage preservation. Examples of approaches to improve seismic performance of vulnerable buildings are explored. We conclude that significant gains in seismic risk reduction can be achieved in the short term for owners of high risk buildings by focussing on the most critical vulnerabilities, with further improvements to progressively improve the seismic performance over time, in contrast to strengthening a building to a high aspirational target over a longer period of time.

The paper then presents several case studies to demonstrate the practical application of a seismic risk reduction strategy. Examples include a heritage listed church and an urban streetscape. We conclude that strengthening and heritage preservation are not mutually exclusive, but rather through the development of cost effective retrofit schemes implemented in a sensitive and skilled manner, both improved life safety outcomes and preservation of our heritage buildings can be achieved.

1. Introduction

The 2010–2011 Canterbury earthquake sequence and the more recent Grassmere, Seddon and Castlepoint earthquakes have raised public awareness of the risk earthquakes pose to the New Zealand community. They have generated intense interest in building performance throughout the nation. Heritage buildings and character precincts have been identified as particularly vulnerable. Significant damage was suffered by some heritage buildings in the recent earthquakes and as a consequence some of these valued buildings have been demolished.

What options do we have to retain New Zealand's heritage buildings and character precincts?

This paper examines key issues associated with heritage buildings and character precincts located in seismic zones, and identifies some of the key lessons learnt from the recent Canterbury earthquakes regarding our built environment from a structural engineer's viewpoint. The paper then suggests pragmatic approaches to manage the risks and strengthen these valued buildings in our communities.

2. The Canterbury Earthquake Sequence

The 2010–2011 Canterbury earthquake sequence started with the 4 September 2010 M_w7.1 Darfield earthquake. It caused moderate damage in Christchurch particularly to older unreinforced masonry and stone (URM) buildings, including a number of heritage buildings. A local state of emergency was declared immediately after the earthquake and a programme of rapid safety evaluations were carried out. Some streets and areas around damaged buildings were cordoned off. This process, or a variant of it, was repeated after each of the subsequent aftershocks, including the Boxing Day 2010 aftershock which caused further damage especially to Christchurch's URM buildings. This meant that many heritage buildings were unoccupied and cordoned off when the 22 February 2011 earthquake struck. Undoubtedly, this saved lives.

The Canterbury earthquake sequence has significantly lifted New Zealander's awareness of the potential impact of earthquakes on the built environment, and thus on their businesses and the national economy. It has also shifted the public and corporate appetite for earthquake risk. The result is that questions are being asked about the performance of existing buildings throughout New Zealand.

Tenants are concerned about the safety of the buildings they occupy or plan to lease. In addition to being concerned about the safety of building occupants, a landlord's commercial position is in most cases directly impacted by the anticipated performance of their building, with low rated buildings proving difficult to tenant, insure and borrow against, adversely impacting the capital value associated with a property. Insurance companies are concerned about the risk their portfolios present. These market drivers were largely absent prior to 2010.

3. Lessons learnt

The government responded to the concerns of the community by establishing the Canterbury Earthquakes Royal Commission. The Royal Commission's brief was to investigate the performance of a representative sample of buildings in Christchurch's central business district (CBD), and to look at the legal and best practice requirements for the design, construction and maintenance of buildings throughout the country to address the known risk of earthquakes.

After more than a year of hearings and investigations, the Royal Commission issued its findings and recommendations in late 2012. These included:

- An active nationwide programme be instituted to identity all "earthquake prone buildings".
- That earthquake prone buildings be remediated by strengthening or demolition within a nominated time frame.
- Changes to the building code to address identified deficiencies.
- Changes to the post disaster building assessment and placarding process.
- Changes to the occupational regulation of the engineering profession.

The Government has considered these recommendations and has introduced into Parliament proposed amendments to the Building Act for the assessment and strengthening of all New Zealand buildings. The proposed changes will require all buildings to be assessed within five years to identify whether or not they are earthquake prone, and will then require buildings identified as earthquake prone to be strengthened to at least 34% New Building Standard *(%NBS)* within a further 15 years. Owners of New Zealand Heritage List Category 1 heritage buildings will be able to apply for an extension of a further 10 years.

These timeframes and strengthening levels are proposed to apply nationally. This is a change from the existing arrangement where triggers for assessment and strengthening including timeframes are determined by the various local authorities. No change to the definition of an earthquake prone building or the minimum required strengthening level has been proposed (i.e. 34*%NBS* is intended to remain as currently).

4. Possible Impacts on New Zealand's built heritage

The key driver for these proposed Building Act amendments is to improve life safety in the event of an earthquake. Community concern about life safety is understandable given 185 people [1] died as a result of the 22 February 2011 Christchurch earthquake.

Economic interests also have to be considered. The consequences of closing a major metropolitan area for an extended period have been clearly demonstrated by the "red zone" in Christchurch. New Zealand's economy would clearly be very significantly affected if a natural disaster closed Auckland's or Wellington's CBD for a similar period.

Figure 1: Enforcing the cordon around the CBD in Christchurch following the 22 February 2011 earthquake.

Fortunately most buildings in Christchurch (over 85% [2]) were well insured at the time of the earthquakes, and insurance payments are now being used to fund repairs and rebuilds throughout the city. The insurance companies have made changes following the recent earthquakes, responding by rewriting policies and limiting the levels of cover in some instances. The availability of insurance for older, lower-graded buildings has been diminished and both premiums and excesses have increased. This will impact funding for repairs or rebuilds following any future disaster.

The options for building owners with earthquake prone buildings are limited. Address the seismic risk and strengthen, or demolish and rebuild with consequent loss of heritage and character values.

This focus on improving the seismic performance of the New Zealand built environment by requiring improvement of the lowest graded buildings presents a significant potential threat to our heritage buildings and character precincts if the net result is widespread demolition of these buildings.

Older buildings frequently play a key role in terms of community amenity, but achieve low financial returns. Consequently, as structural engineers we are often asked if both strengthening and heritage preservation can be achieved.

This paper advocates that it is practical to strengthen older buildings to address both life safety concerns and the possible economic consequences of a significant earthquake, while also preserving key heritage elements of the building, within the context of the relatively low yields these buildings provide for their owners.

5. Reducing Seismic Risk

5.1. Seismic risk

Seismic risk is commonly defined in New Zealand as the performance of the subject building relative to a new building designed to the current code. The result is expressed on a percentage basis, *%NBS*.

Table 1: Seismic risk grade based on %NBS.

Designation as per Building Act 2004	Percentage of New Building Standard (*%NBS*)	Seismic Grade	Relative Risk
Low Potential Earthquake Risk Building (*%NBS* >=67)	> 100	A+	< 1 times
	80 – 100	A	1 – 2 times
	67 – 80	B	2 – 5 times
Earthquake Risk Building (*%NBS* <67)	34 – 66	C	5 – 10 times
Earthquake Prone Building (*%NBS* <=33)	20 – 33	D	10 – 25 times
	< 20	E	> 25 times

While this approach provides a simple way to identify buildings most at risk from a life safety viewpoint, it does not explicitly articulate the relative seismic risk between the different buildings with different *%NBS* scores. It fails to clearly identify that improving the seismic performance of a very low graded building by a certain percentage yields a significantly greater benefit in seismic risk reduction terms than improving the seismic performance of a higher graded building by a similar percentage, as illustrated in Figure 2.

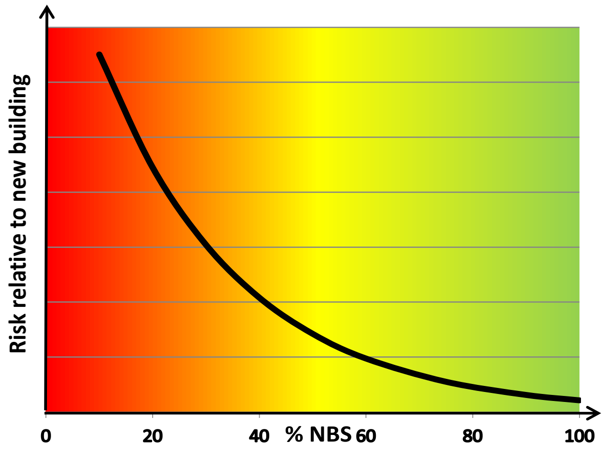

Figure 2: Change in relative risk versus %NBS.

An analysis of URM building strengthening versus fatality risk to building occupants in the 22 February 2011 earthquake completed by T Taig for the Ministry of Business, Innovation and Employment in 2012, [3] concluded that the greatest benefit in life safety risk reduction terms is very clearly achieved by focussing on the lowest graded buildings (i.e. those <33*%NBS* and upgrading them to >34*%NBS*, compared with further strengthening to 67*%NBS*).

5.2. Seismic risk and older buildings

Many heritage buildings and buildings in character precincts in New Zealand share common characteristics. Typically constructed from unreinforced masonry or stone, they generally have timber floors and timber truss roofs supporting lightweight metal roofing. The frontage often includes extensive parapets and external ornamentation.

Observation of the damage suffered by many heritage buildings, (and URM buildings generally), in the recent Canterbury earthquakes reveal a common pattern. This pattern has also been observed in other earthquakes around the world. The chimneys and other appendages frequently fall off the building, gable ends fall out, particularly close to the roof line, and sometimes the walls topple out of plane on to the street.

Figure 3: Typical New Zealand town centre streetscape.

The photo of URM buildings in Figure 3 is typical of character precincts in many towns throughout New Zealand. These buildings were generally constructed between the 1900s and 1930s and consist of two stories of unreinforced masonry construction, with a parapet, a fairly open shop front facing the street on the ground level, and residential/office space above, with windows in the street facing wall. Typically verandas extend over the pavement. While the verandas were often originally supported on posts at the curb edge, in an effort to improve traffic safety these have mostly been replaced over the years with tension rods anchored back into the street facing masonry brick wall.

A large proportion of these URM buildings are currently under 34*%NBS* [4, 5] and pose a potential risk to passers-by of falling onto the street under even a moderate earthquake. In the 22 February 2011 earthquake, 35 deaths were caused as a result of the façade or walls of URM buildings falling onto the street or onto adjacent buildings [5]

Figure 4: Colombo Street, Christchurch after the February 2011 earthquake.

6. Staged Seismic Strengthening

6.1. Three stages

We suggest that seismic strengthening of low graded buildings can be considered as comprising a series of distinct steps. These may be implemented progressively to achieve an improvement in performance over time. The most cost effective and high value strengthening (from a risk reduction perspective) is given the highest priority. Additional strengthening can be added later to further raise performance as redevelopment or adaptive reuse opportunities arise, or as funds allow. This provides an approach to progressively improve the performance of a building over the longer term.

The three strengthening steps or stages are categorised as:

Stage 1 – Securing Work
Stage 2 – “Sweet Spot” Target Strengthening
Stage 3 – Aspirational Target Strengthening.

6.1.1. Securing Work

Secure or remove the most vulnerable building components, for example, chimneys, parapets, finials, large gables, etc.

It was observed in the Christchurch earthquakes that unreinforced masonry buildings with only a limited level of seismic strengthening (e.g. interim securing) performed significantly better than similar buildings without any strengthening work [5, 6], thus reducing the life safety risk of these buildings.

It is anticipated these elements (e.g. chimneys, parapets, ornaments, large gables etc.) can be secured relatively quickly, at reasonable cost, and often with minimal or limited intrusiveness to the building fabric.

It is not necessarily expected securing work alone will improve the performance of the building above “earthquake prone” if it lies in a high seismicity zone. But it will serve to significantly reduce the risk of harm in a moderate earthquake.

We note “interim securing” is a strategy previously recommended by the New Zealand Society for Earthquake Engineering (NZSEE) 1985 Guidelines [7] for the seismic strengthening of URM buildings.

6.1.2. ‘Sweet Spot’ Target Strengthening

Strengthen, mobilising the potential of the existing building fabric as much as possible, augmented with cost effective, pragmatic structural solutions. Add resilience and stabilise.

Low intervention techniques to improve building performance using the potential of the building are well proven. They may involve for example:

- Tying the walls to the roof and floors
- Augmenting the floors so they act as effective diaphragms to transfer loads to the wall elements.
- Confining and stabilising key gravity supports

Each building will have a different ‘sweet spot’ which is generally the maximum performance level achievable without major intervention or significant new structural elements. We anticipate for many buildings throughout New Zealand, ‘sweet spot’ strengthening will raise the level of seismic performance of the building to a least grade C (between 34*%NBS* and 67*%NBS*), although this may not be the case for older buildings in areas of highest seismic risk.

While it is anticipated this level of strengthening will be more intrusive and expensive than the ‘securing’ stage for many buildings, never-the-less this stage will yield significant life safety benefits in seismic risk reduction at reasonable cost.

6.1.3. Aspirational Target Strengthening

Consider strengthening to an aspirational performance target as funds, priorities, and opportunities allow.

Aspirational target strengthening beyond 'sweet spot' strengthening will inevitably involve more invasive and extensive strengthening techniques whereby new structural systems are added to the building to augment or replace the existing structural system.

The NZSEE guide on the Assessment and Improvement of Buildings in Earthquakes [8] suggests improvement to at least 67*%NBS* should be the aim. However, it notes the underlying aim of the legislation is "to cause a reduction in earthquake risk represented by existing buildings". It further notes that it is better to do something rather than nothing, to reduce seismic risk (while of course also meeting NZ legislative requirements for improvement to above the earthquake prone level within the mandated timeframes).

6.2. Benefits of a Staged Strengthening Approach

A staged, progressive approach to seismic strengthening provides a way to improve the seismic performance of a high risk building over time, by doing something in the short-term to start to reduce the seismic risk, then implementing additional measures later to further improve the building performance. These additional works could potentially be planned to coincide with a general refurbishment, change of tenant or change in use.

Importantly, any strengthening or securing work installed should be compatible with future stages. For example, wall restraint anchors installed in the securing stage should be sized for the accelerations the building might ultimately be capable of when extra diaphragm or wall improvements are made at a later stage. This may mean some redundant capacity initially, but components such as anchors are not expensive compared to the high labour and make-good costs incurred if the same area had to be uncovered a second time.

6.3. Relative Costs

An analysis of seismic strengthening costs indicates that often a moderate improvement in the performance of a low graded building can be achieved relatively inexpensively, whereas a more expensive intervention is often required to lift the building performance closer to the new building standard. This is illustrated when considering seismic strengthening of unreinforced masonry buildings which are frequently amongst the lowest graded buildings in New Zealand.

Removing falling hazards like chimneys, bracing parapets (securing work) and tying the roof and floors to the walls and improving the floor diaphragms (sweet spot strengthening) are relatively low cost interventions which yield significant gains in seismic risk reduction. Seeking to improve the seismic performance further may entail new structural systems to increase the in-plane capacity, necessitating more extensive interventions (such as wall overlays or supplementary frames) which are more costly in comparison. Our experience indicates that a straight linear relationship does not exist between seismic strengthening costs and improvements in seismic risk reduction or seismic grade. This is illustrated in Figure 5

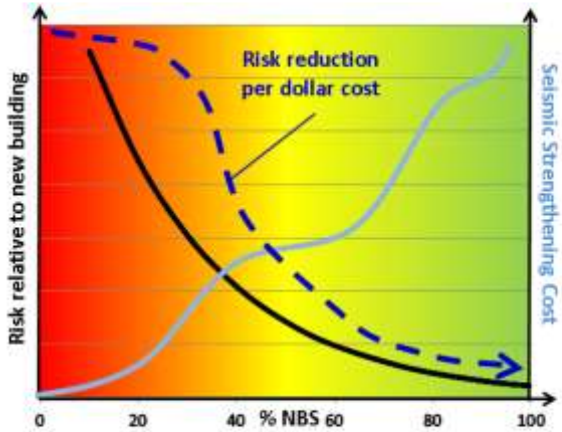

Figure 5: Comparison of risk reduction and cost of solution versus %NBS.

7. Case study – King's College Memorial Chapel

Figure 6: King's College Chapel west elevation.

The progressive strengthening of the King's College Memorial Chapel in Auckland, which has been underway for some years, provides an illustration of a staged strengthening approach. The chapel is part of a portfolio of buildings comprising the College campus, some of which are currently in the process of being strengthened in a staged manner.

The chapel was constructed in the mid-1920s as part of the original construction of the King's College campus when it moved to Otahuhu. It has a floor-to-ceiling height of 14.5 metres and was originally constructed in unreinforced masonry with a heavy slate roof. Built as a memorial to the former pupils of the College killed in World War I, the building contains many significant historic and memorial features, including large stained glass windows and extensive timber panelling.

Figure 7: King's College Chapel interior.

It is listed as a Category 1 historic place by Heritage New Zealand, and is listed in the Auckland Council District Plan as a Category A heritage place.

7.1. Securing work

The building was assessed in the early 1990s and identified as being significantly deficient in seismic capacity. A programme of securing work was undertaken progressively between 1992 and 1995. This involved adding a ply roof diaphragm under the roof tiles, connecting the walls to the roof diaphragm, adding tension ties to the roof trusses, adding a concrete ring-beam at parapet level and some buttress foundation improvements.

An assessment of the building completed more recently as part of a seismic assessment review of all College buildings confirmed these 'securing' strengthening works had lifted the building performance sufficiently that it is no longer considered earthquake prone, but remains an earthquake risk.

7.2. Sweet spot strengthening

Further 'sweet spot' strengthening is currently being planned with the aim of elevating the seismic performance to the 40–50%NBS range (refer Figure 8). These strengthening measures seek to utilise existing building elements as far as possible, minimising the impact on the historic fabric.

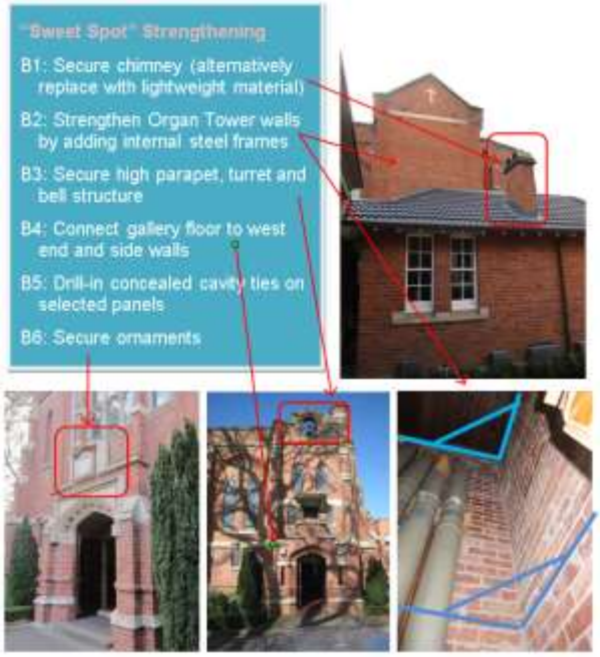

Figure 8: King's College Chapel Sweet Spot Strengthening.

7.3. Aspirational Strengthening

Further potential aspirational strengthening measures have also been identified to further lift the performance of the building, with due consideration of the implications to the many heritage features. These involve more invasive measures as indicated in Figure 9.

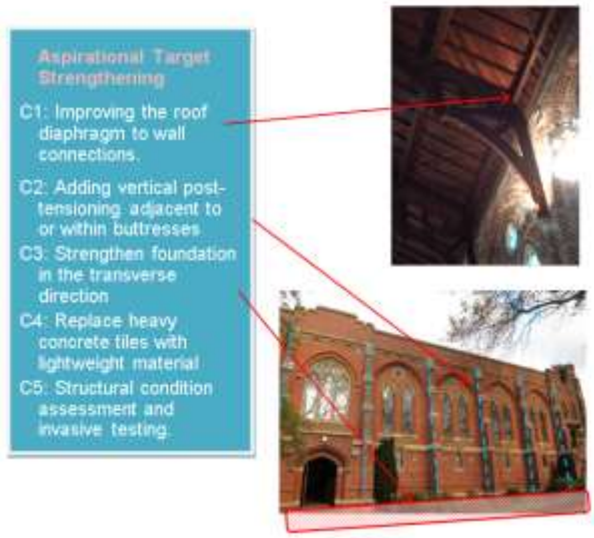

Figure 9: King's College Chapel Aspirational Strengthening.

8. Case study – Typical Pre-war Streetscape

The efficiencies and advantages of the advocated systematic and staged approach can be further illustrated using the example of a typical New Zealand streetscape of pre-war vintage as shown in Figure 3. From a public safety viewpoint, it is more relevant to consider the risk of the group of buildings rather than the risk from an individual building.

The first and most urgent task for this group of buildings would be to ensure that they all reach the “secured” level. This might be achieved by bracing the parapets to the roof, and also tying the street facing wall to the roof and first floor (as shown indicatively in Figure 10).

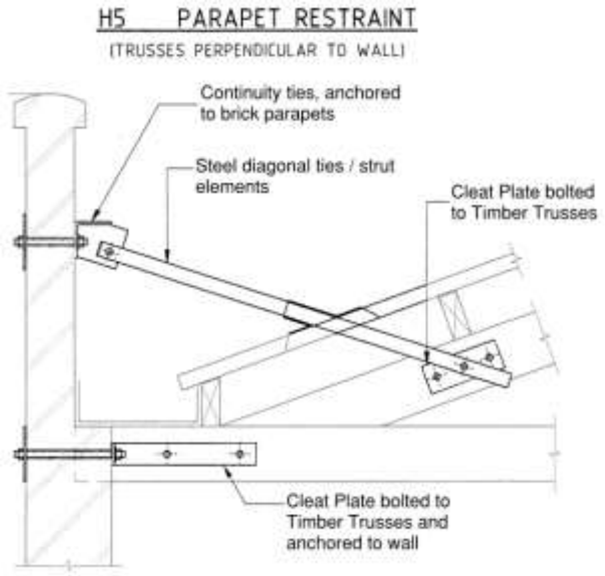

Figure 10: Example of parapet bracing and wall anchor solution for a URM wall (from NZSEE, 1995 [8]).

If we assumed the building’s seismic performance was in the order of 20*%NBS* before the intervention we might anticipate the addition of the connections, as noted above, will likely raise the seismic performance to above 34*%NBS*.

Using our typical streetscape example based on 10 similar buildings, one can compare the total risk reduction achieved across the group for several different strengthening options based on spending the same overall amount.

- Option A; Upgrade two buildings to 80*%NBS* and leave the rest at 20*%NBS*
- Option B: Upgrade four buildings to 67*%NBS* and leave the rest at 20*%NBS*
- Option C: Upgrade all 10 buildings to 34*%NBS*.

The benefit of ‘securing’ all 10 buildings in our example as a first priority and as a collective, rather than piecemeal to different levels of performance is clearly illustrated in Figure 11.

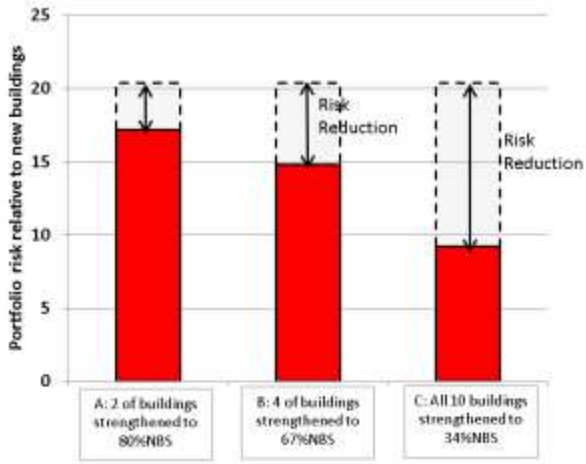

Figure 11: Three options for risk reduction across a group of similar buildings based on the same overall level of expenditure.

8.1. Possible Efficiencies

Raising the seismic performance of many of the typical low graded buildings above earthquake prone often involves relatively simple interventions to be undertaken. There is the possibility of considerable efficiency gains given the similarities of many of the buildings, and standardisation of the retrofit works.

There is also the possibility of sharing significant engineering, procurement and management costs across a collection of similar buildings not owned by a single owner. This would have the effect of significantly reducing costs to individual building owners, thus providing encouragement to enact the strengthening works.

For lower seismic risk areas of New Zealand we consider it would be possible to develop a “deemed to comply” regulatory approach for many of the typical older buildings, such as our streetscape example, whereby, provided an owner installed a required standard group of strengthening measures, they are deemed to have met the requirements to remove the earthquake prone status from their building. This would avoid extensive assessments for each individual building, and the development of bespoke strengthening designs for each, with a resultant reduction in costs for building owners.

This is the approach San Francisco has taken over a number of years. They first required a parapet bracing ordinance to be implemented whereby all street facing parapets on pre-1949 URM buildings were required to be braced and the tops of the walls be tied into the roof diaphragm. This was followed more recently by further ordinances known colloquially as “bolts plus” and “bolts plus plus”. These ordinances require wall to floor diaphragm anchorage and out of plane wall bracing if walls do not meet certain aspect ratios.

This series of ordinances are designed to progressively lift the life safety performance of URM buildings across the city by focussing on what are known to be the most significant issues first, and then going on to address the next most significant issues, whilst keeping it affordable and practical for building owners to undertake the work.

San Francisco has not seen widespread demolitions as a result of requiring this work to be completed. Consequently, the heritage character of the city is being preserved while improvements to reduce the life safety risk are being enacted.

9. Strengthening Objectives for Heritage Buildings and Character Precincts

Selecting the strengthening objectives for a particular building or portfolio of buildings can be challenging. While earthquakes are rare events, the consequences on a building can be severe from a life safety viewpoint as well as a heritage preservation viewpoint.

Often the need to deal with the lowest performing buildings is seen as urgent, but sometimes the performance target set by the organisation is at such a level that individual project costs become prohibitively high. A stalemate scenario can arise whereby no action is taken. This can happen, for example, when seismic performance targets are set without an appreciation of the total cost, or when other issues such as refurbishment needs become apparent. As a consequence, some poorly performing buildings with issues that could be readily rectified reside in the “too hard basket” for extended periods of time.

From the perspective of seismic strengthening we contend the pursuit of inflexible and high *%NBS* targets can be counterproductive. Each building will have a different risk profile and ‘sweet spot’, where the maximum risk reduction is achieved for a given outlay.

Different strengthening objectives may be appropriate for different building typologies, and staged strengthening provides the opportunity to progressively improve the seismic performance of buildings over time.

A staged strengthening approach provides a mechanism for New Zealand’s built heritage to be preserved, while also addressing the public’s concern for seismic risk reduction. By implementing simple, relatively low cost, interventions the seismic performance of older buildings can be significantly improved, whilst simultaneously reducing life safety risk and addressing the legislative requirement to lift buildings above the earthquake prone level (≥34*%NBS*). They can be further strengthened later to a higher level as appropriate.

Demolition of many of our older buildings can be avoided, thus preserving our built heritage. In the event of a significant earthquake these strengthening interventions will improve the performance of the buildings, although they may not be undamaged and may require repairs or demolition, depending upon the severity of the earthquake.

This approach is thought to be particularly appropriate for character precincts and other older buildings which face an immediate threat of being demolished or abandoned in the face of legislative requirements to strengthen, and the anticipated costs to do so.

For selected buildings, (for example Category 1 historic places) it seems appropriate to consider strengthening both to reduce life safety risk and to protect property. This may be implemented in a staged manner over time and does not necessarily have to be completed in one step. This approach provides a way to protect buildings by improving their life safety performance to meet the legislative requirements and then progressively strengthening the building further to protect them from damage in the event of an earthquake as funds and priorities allow.

10. Conclusion

The recent earthquakes in New Zealand have highlighted the vulnerability and risk to life safety of some of the existing building stock across the country, particularly our older heritage buildings and character precincts.

We consider a pragmatic approach is required to seismic risk reduction, with a focus on giving the highest priority to the most cost-effective and high value strengthening (from a risk reduction perspective). By improving the lowest graded buildings, even by only a moderate amount, significant gains in life safety risk reduction are achieved.

We consider this is both practical and achievable. Our analysis of many buildings we have strengthened indicates that often moderate improvement in the performance of a low-graded building can be achieved relatively inexpensively, and this moderate improvement yields a significant reduction in life safety risk.

Significant cost efficiencies can be gained by standardised designs, sharing engineering procurement and management of strengthening costs across a group of buildings, and by developing a “deemed to comply” securing regulatory approach to minimise bespoke engineering designs and facilitate implementation.

Strengthening and heritage preservation are not mutually exclusive. With education on relative risks, and a positive, pragmatic approach to seismic strengthening, New Zealand's buildings can be strengthened resulting in retention of our built heritage.

11. Acknowledgement

We would like to acknowledge King's College for kindly allowing us to share the example of strengthening the College Chapel in this paper.

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WELLINGTON CABLE CAR AND ITS ENGINEERING HERITAGE

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Abstract
Wellington's iconic Cable Car is a fully functioning funicular railway that carries in excess of 1,000,000 passengers per annum. It serves a dual purpose as a vital transport link between Lambton Quay and Kelburn, and as the second most popular tourist attraction in Wellington. It first opened in 1902 and has recently been the subject of an application for an Institution of Mechanical Engineers Heritage Award. It was designed by James Edward Fulton who, assisted by Maurice O'Connor, constructed the 785 metre (m) system, rising over 119m at an average incline of 1 in 5. At the time, it was a major engineering achievement for New Zealand and the railway track passes through three tunnels and over three viaducts. Despite being commonly referred to as a Cable Car, the original system used to operate the ascending and descending cars was in fact a combination of a cable tramway and a funicular. In 1978, the original system was extensively modified and the drive system and passenger vehicles were replaced with the current Garaventa-designed system. The original twin railway tracks were replaced with a single track plus a crossing loop. The drive system was replaced with a variable Direct Current (DC) electric drive and the track length was reduced slightly to 610m. The Cable Car reopened in 1979 and has run in its current form since then.

1. Introduction

This paper is a synopsis of a recent application to the Institution of Mechanical Engineers (IMechE) for an Engineering Heritage Award for Wellington's iconic Cable Car that has proudly and reliably served Wellingtonians since 1902. [1]

Wellington Cable Car Limited (WCCL) operates and maintains Wellington's historic Cable Car (which is a funicular railway) and the city's iconic Trolley Bus DC overhead electrical network. WCCL is a Wellington City Council-owned Council Controlled Organisation, incorporated in 1991. [2]

This application was supported by the Institution of Professional Engineers New Zealand (IPENZ) Mechanical Engineering Group (MEG) national executive committee. The MEG is a Special Interest Group which also represents IMechE's interests in New Zealand.

2. Background Information and History

Wellington's iconic Cable Car is a fully functioning funicular railway. It carries in excess of 1,000,000 passengers per annum and serves a dual purpose as a vital transport link between Lambton Quay and the suburb of Kelburn, and as the second most popular tourist attraction in Wellington. It is often featured on promotional images gradually ascending towards Kelburn, with the central business district (CBD) laid out below. However, for many local residents and students, the Cable Car remains an important form of daily transportation.

The Cable Car has served the Wellington general public faithfully since opening in 1902 and was the brainchild of two Scottish immigrants, John Kirkcaldie and Lewis Henry Balfour Wilson, who were instrumental in many of the key buildings, and supporting infrastructure, constructed within the CBD. Further reference to their activities is documented in the Wellington City Council publication "*Wellington's Old Shoreline Heritage Trail*". In the 1890s, Wellington was the fastest growing city in New Zealand and was becoming increasingly crowded. Speculators saw the opportunity to develop new suburbs beyond the town belt, including Kelburn. [3]

They formed the Upland Estate Company which purchased the land on which the Cable Car was eventually built, and subsequently incorporated the Kelburn and Karori Tramway Company to design, build and run a funicular railway. This was intended to service the growing suburb of Kelburn, as well as what was destined to be the main campus of Victoria College (which is now Victoria University of Wellington).

Kirkcaldie and Wilson, assisted by a fellow Director, Martin Kennedy, engaged a brilliant engineer by the name of James Edward Fulton to design the Cable Car. It was his engineering skill and dedication, assisted by the construction skills of Maurice O'Connor who brought to life the Cable Car which, with some modifications, is still running today.

Fulton was associated with the Upland Estate Company from early in its history. His design was described as a complicated piece of work featuring tunnels, viaducts, and retaining walls. Fulton also designed the necessary machinery and safety appliances for handling the traffic.

At the time of his death in 1928 Fulton was said to be one of the best known engineers in the Dominion and the Cable Car was seen as one of his biggest achievements. [4]

Figure 1: Wellington's Cable Car is the second most popular tourist attraction in the capital city after the Museum of New Zealand, Te Papa Tongarewa and carries in excess of 1,000,000 passengers per annum.

3. Geography and Geotechnical Conditions

Wellington's undulating geography and the requirement to pass over or under all existing roadways, allowing for uninterrupted passage, predicated a track length of 785m rising over 119m at an average incline of 1 in 5. At the time, it was a major engineering achievement for New Zealand and the railway track passes through three tunnels and over three viaducts. The Cable Car has five stations including the top and bottom terminals of Kelburn and Lambton Quay, plus the intermediate stations at Salamanca, Talavera and Clifton Terrace, and these remain in use today. [5]

A funicular railway is a good design option where the geotechnical conditions and topography, although challenging, are such that a railway track can be laid.

This gives the technical advantages of greatly increased payloads, a higher degree of lateral stability for the passenger vehicles and enhanced passenger safety in the event of a significant incident. The most common equivalent of a funicular railway in widespread use nowadays is the Gondola manufactured by companies such as Doppelmayr and Poma. These are most often found in ski resorts and tourist destinations. [6]

A significant amount of explosives blasting was the main technique utilised to carve the route for the Cable Car's three tunnels that are still in use today. Despite Wellington's close proximity to an earthquake fault line, the traditional tunnel construction techniques and tunnel portals have stood up extremely well to over 100 years of constant, low order seismic activity.
The tunnels are inspected annually for structural integrity and any change in alignment is detected by monitoring strain gauges fitted in the tunnels. The higher magnitude earthquakes that occurred in July and August 2013 had a negligible effect on alignment and nil damage was caused as a result.

For the viaducts, Fulton was innovative in his use of scaffolding techniques and deviated away from the standard construction practices at the time, which was to build up from the bottom of the valley. He managed to save a considerable amount of programme time and expense by securing much of the scaffolding into the side of the hills, whilst still ensuring the safety of construction workers building the viaducts.

Figure 2: Kelburn Kiosk, Wellington, New Zealand, circa 1908, Wellington, by Muir & Moodie. Purchased 1998 with New Zealand Lottery Grants Board funds. Te Papa (PS.001360/02). Retrieved 04 November 2014, from http://collections.tepapa.govt.nz/Object/327307

4. Choice of Motive Power and Track Configuration

Initially the preferred means to power the Cable Car was using a water-balanced system (the Lynton and Lynmouth Cliff Railway in Cornwall is a surviving example of this). The system concept was for two counter-balanced cars, each with a large water tank. The car at the upper station had its tank filled with water allowing gravity to pull the lower car upwards as it descends. There were however, a number of drawbacks to this system and the idea was eventually scrapped in favour of a steam-driven power source. This lasted until 1933 when it was replaced by electricity to overcome problems caused by a lack of installed power and long-term increases in weight of the Cable Cars (and the passengers). To house the engine a two storey winding house, also designed by Fulton, was built at the Upland Road terminus. The smokestack would eventually become a Wellington landmark and its smoke plumes were relied on as an indicator of wind direction. [7]

The former Winding House is now a dedicated Cable Car Museum, housing some of the original system‘s equipment, and a car designed and built by Dunedin‘s tramcar specialist, Mark Sinclair. [8]

Despite being commonly referred to as a Cable Car, the original system used to operate the ascending and descending cars was in fact a combination of a cable tramway and a funicular. The system made use of two cables; the driving cable which would tow the descending car downhill and the tail wire which connected the two cars. The momentum of the descending car would haul the second car uphill through the connected tail wire. The term ‘cable car’ could therefore only be technically applied to the descending car as it was only on the downhill journey that the cars gripped the driving cable. [9]

Originally the line consisted of double track which ran along the route between the Lambton Quay terminus and the Upland Road terminus at a length of 785 metres (m). The tracks consisted of the New Zealand standard railway gauge of 1,067 millimetres (mm) and were set at 2.7 m centres. When the line was subsequently rebuilt in 1979, the tracks were changed to the common European narrow gauge of 1,000 mm. [10]

5. System Redesign and Upgrade in 1978

With the exception of the drive system and motive power, the original Cable Car system remained in service and largely unchanged until 1978. The original passenger vehicles (which were nicknamed the "Red Rattlers") were loved by generations of Wellingtonians as their open design allowed passengers to sit facing outwards and kick the tunnel walls whilst travelling through the tunnels. [11]

Figure 3: One of the "Red Rattlers photographed in 1973 stopping at Talavera station.

An increasing awareness of legislative responsibilities for passenger safety, plus technical obsolescence after 75 years of service meant a fundamental redesign was required. Despite an outcry from the general public, the decision was made in 1973 that an upgrade was essential to deal with acute obsolescence issues that were adversely affecting engineering support and reliability. In 1978, the original system was extensively modified and the drive system and Cable Car bogies and passenger cars where replaced with the current Garaventa-designed system. The original twin railway tracks were replaced with a single track plus a crossing loop at the midway station. [12]

The outside wheels of the bogies on the Cable Car vehicles are handed such that each vehicle always goes the same way on the crossing loop, eliminating the requirement for track points.

The drive system was replaced with a 185 kilowatt variable DC electric drive and the track length was reduced slightly to 610 m. The Cable Car reopened in 1979 and has run in its current form since then, although replacement of the electric drive and associated control and telemetry systems is planned for 2016 to, again, deal with long-term weight increases and obsolescence.

The "new" design was considered revolutionary at the time although its control system pre-dates the introduction of personal computers and the use of Supervisory Control and Data Acquisition (SCADA) systems to enhance the Human Machine Interface (HMI).

The current Cable Car passenger vehicles have a mass of 13 Tonnes each and carry a maximum of approximately 75 people per car (maximum loading of 7 Tonnes per car. The maximum velocity is 5 m/s and the Cable Car transit time is 7 minutes if it stops at all the intermediate stations. [13]

Figure 4: The redesigned crossing loop at the midway Talavera Station introduced in 1979.

6. Risk Management

WCCL, the modern day successor to Wellington City Transport Limited, risk manages the Cable Car by a variety of means, including legal as well as technical / structural and operational. WCCL is also subject to the provisions of the Health and Safety in Employment Act 1992 and the proscriptive regulations enacted under the legislation for passenger ropeways (which includes Cable Cars). [14]

As a fully functioning funicular railway carrying in excess of 1,000,000 passengers per year, WCCL is required to comply fully with the provisions of the Railways Act 2005. This requires the Company to present annually to the New Zealand Transport Agency a detailed and updated safety case. This demonstrates that the Cable Car is correctly maintained and that appropriate safe systems of work are in place to protect passengers and staff in the event of any incidents. Part of this includes an annual shut-down for maintenance, including a rolling passenger vehicle bogie replacement, and thorough testing of the various propulsion and braking systems utilising all the various modes of redundancy. [15]

From a technical / structural perspective, the continued safe operation of the Cable Car, including meeting our specified service standards and reliability targets are addressed by the Cable Car's asset management strategy and its associated asset management plan. This includes ensuring high engineering standards through a sensible and affordable balance of regular inspections, appropriate preventative maintenance, and replacement of capital items when required by service life or a condition based regime.

Finally, operational risk management is also enhanced by the deliberate policy decision to continue using Cable Car drivers instead of automating the operation (which would be relatively straightforward to do). This ensures that trained and experienced staff (who are also first aid trained) are immediately on hand in the event of a service stoppage or other incident, which is particularly important while the Cable Cars are transiting the tunnels. This also has a very positive benefit in terms of ensuring that good interpersonal contact is maintained with the passengers.

Figure 5: The new Kelburn terminus built in 2013.

7. Conclusion

Wellington's iconic Cable Car is a fully functioning funicular railway essential within the city's public transport network and one of the capital's popular tourist attractions. It has served the Wellington general public faithfully since opening in 1902.

The Cable Car is recognised as one of important engineer James Edward Fulton's major works. It conquers the challenging landscape between Lambton Quay and the hill suburb of Kelburn through a series of tunnels and viaducts and a combination of cable car and funicular railway. With some modifications, Fulton's Cable Car is still running today and, as at the time it was constructed, it is regarded as one of New Zealand's engineering achievements.

WCCL risk manages the Cable Car and is ensuring the retention of this piece of engineering heritage by a variety of means, including meeting regulatory and legal requirements. From a technical / structural perspective, the continued safe operation of the Cable Car, including meeting our specified service standards and reliability targets, is addressed by the Cable Car's asset management strategy and its associated asset management plan. Finally, operational risk management regarding service stoppages or other incidents is also enhanced by the deliberate policy of using specially trained Cable Car drivers, instead of automating the Cable Car operation.

Figure 6: The Cable Car runs over the viaduct at Salamanca near Victoria University of Wellington.

8. Acknowledgements

The author acknowledges the help and assistance of the following organisations and personnel with the research associated with writing this paper – Wellington Cable Car Limited (Matthew Hardy and Gavin MacIntyre), Wellington Museums Trust (Wellington Cable Car Museum), IPENZ (Engineering Heritage Register) and Simon Daisley (author of the Wellington Cable Car IPENZ Engineering Heritage Register Report).

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THE STRENGTHENING OF HERITAGE BUILDINGS – CONSTRUCTION CHALLENGES

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Abstract
The task of strengthening and restoring heritage buildings is a challenging one as it is often difficult to strengthen a member without changing its dimensions or otherwise making the structure look different. Furthermore, the commercial realities sometimes dictate that adaptations to a building are needed to ensure its future usefulness. The task of supporting or moving the brittle fabric of heritage structures to accommodate these alterations can be even more difficult requiring thorough investigation and innovative methods. Between 1994 and 2011, the Auckland City Council strengthened and restored five major civic buildings and the author worked on two of these. This paper discusses some examples of the challenging construction aspects encountered in the strengthening and restoration of these heritage buildings.

1. Introduction

Five major civic buildings were seismically strengthened and restored by the Auckland City Council between 1994 and 2011. These were:

- 1994 – 1997 Auckland Town Hall
- 1998 – 1999 Civic Theatre
- 2002 – 2003 Chief Post Office
- 2004 – 2007 Auckland Museum
- 2008 – 2011 Auckland Art Gallery

Construction work on the Town Hall, the Civic and the Chief Post Office was carried out by Downer, and Hawkins Construction carried out the work on the Auckland War Memorial Museum and Art Gallery.

2. Auckland Town Hall

The Town Hall, located in Auckland's Queen Street, was constructed 1910–1911. The restoration which was carried out 86 years later included earthquake strengthening to modern design codes.

Figure 1: Auckland Town Hall, 2011.

Strengthening work included foundation piles, strengthening of concrete slabs and additional lateral support and concrete overlay strengthening to the unreinforced masonry walls.

Installation of the piles became difficult in that some areas had little headroom. Access by a piling rig of any sort could not be achieved, resulting in one of the piles being hand dug.

Figure 2: The Great Hall during refurbishment.

By contrast, the Great Hall was inconveniently large. In order to access the ceiling for painting and restoration, scaffolding of the entire auditorium was necessary.

Lateral support for the walls of the building was typically provided by tying the walls to a "diaphragm" floor or a (plywood strengthened) roof. A key to this philosophy is the anchors used to tie the brick walls to the diaphragm. In the course of the Town Hall project, Downer tested anchors and epoxy resins to destruction to verify their suitability.

A construction method which was new to New Zealand, and driven by the constraints of heritage work, was adopted for the strengthening of the mezzanine concrete floors in the main entrance.

This entailed thin carbon fibre reinforced polymer strips, which were glued to the underside of the concrete slab. This resulted in an improvement in strength without significantly changing the depth so that the architectural features, floor tiles and ceiling heights remained unaltered.

Figure 3: Strengthening work in progress, 1996.

3. Civic Theatre

The Civic Theatre was constructed in 1929 and was restored and strengthened in 1998–1999.

Figure 4: The 40c stamp of the Civic Theatre issued in 1998 while it was undergoing restoration.

The original Civic featured a Wintergarden that was open to the main auditorium's stage. The 1999 refurbishment (as did the 1975 conversion to a small cinema) featured the Wintergarden as a space separate from the main auditorium so that separate functions could run simultaneously.

For the 1999 refurbishment, this meant that some features of the interior had to be raised 2 metres (m).

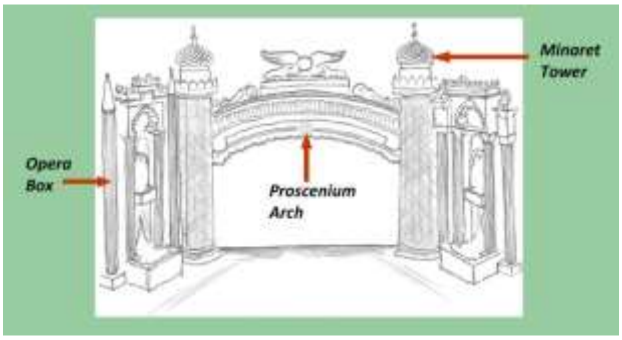

Figure 5: Interior features required to be raised 2 metres.

The two Minaret Towers were de-constructed by cutting them into 3 m high sections, removing them to storage and then restoring and re-constructing them on new, higher bases. This was the suggested method for other interior features, but the process was slow and destructive.

Therefore, the Proscenium Arch was treated differently. In an attempt to keep it in one piece, a pair of monorails was first installed under the roof trusses. The 8.5 tonne arch was then strengthened with steel and timber members and attached to the monorails with electric hoists. Its timber fixings were cut free from the proscenium wall and the arch was rolled towards the centre of the auditorium.

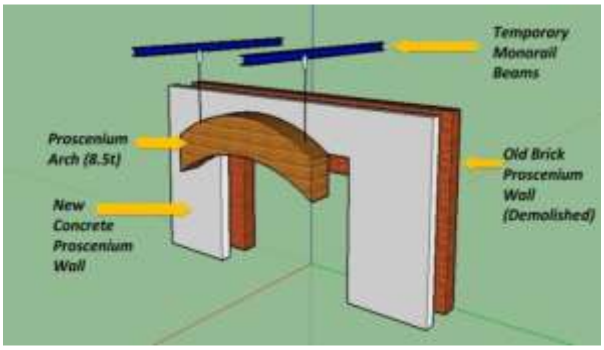

Figure 6: The temporary support, removal & re-attachment of the Proscenium Arch was engineered by Bob Mawdsley.

There it stayed until the new reinforced concrete proscenium wall was complete and the old brick wall demolished. The arch was then rolled back, raised 2 m and fixed to the new proscenium wall.

Figure 7: The Proscenium Arch is suspended from the monorails.

The raising of the Opera Boxes was equally innovative. Once again the objective was to keep the structures in one piece to eliminate time-consuming de-construction and re-construction.

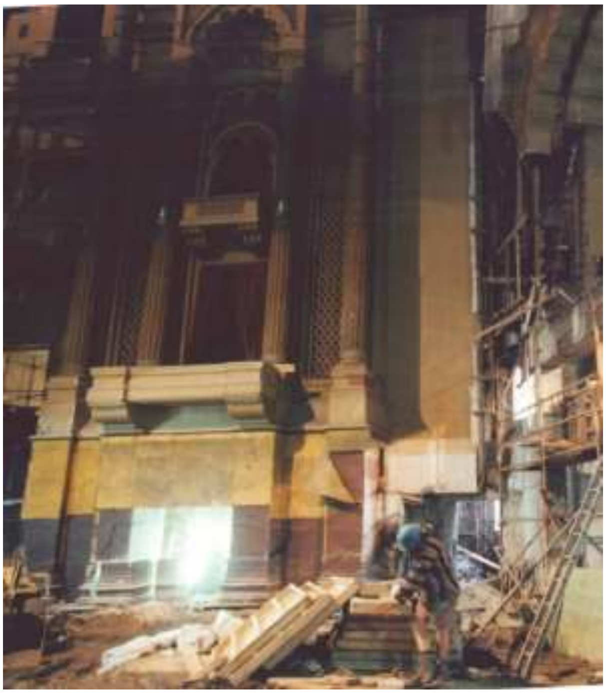

Figure 8: Opera Box Stage Right (before raising).

The proposed scheme involved steel brackets fixed to the walls and vertical rails attached to the structures, meaning the Opera Box could be slid up the wall. A captive shoe-and-channel detail ensured the Opera Box could not come out of its rails.

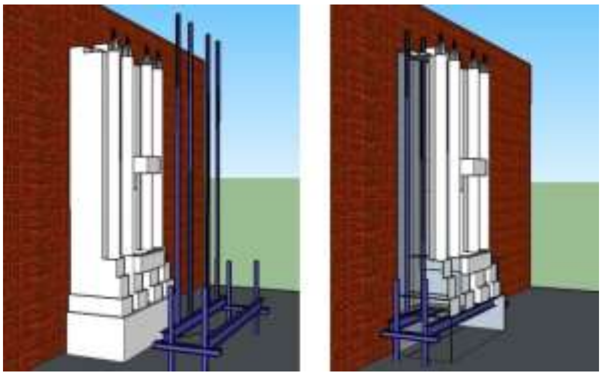

Figure 9: The temporary steelwork structure shown assembled both outside and inside the Opera Box

Whilst the initial concept was simple, the detail was not. Not only were the two Opera Boxes different in style, their make-up of framing timbers was rather random. It was also clear from an early stage that great care was needed to move a structure that was essentially made of flimsy film-set construction. Unless the Opera Box was fully strengthened and supported for the move there was the risk that only handfuls of plaster and wadding would be left attached to the new steel frame! All of the irregular and random timber framing was inspected, measured up and drawn to scale. A steelwork structure was then designed and detailed to suit.

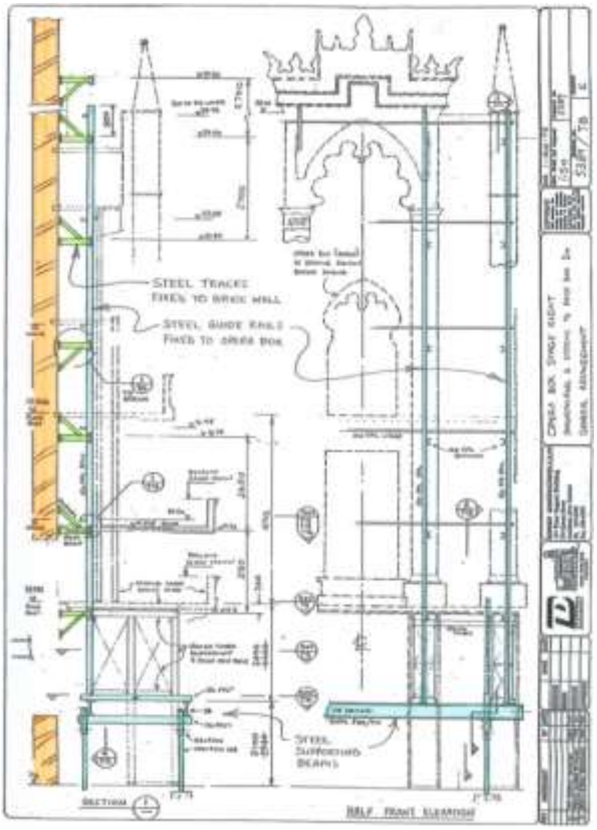

Figure 8: The Temporary Works design for the Opera Box raising, engineered by the author.

With all of the steelwork in place, it was then a straight-forward task to jack the structure up to its final position.

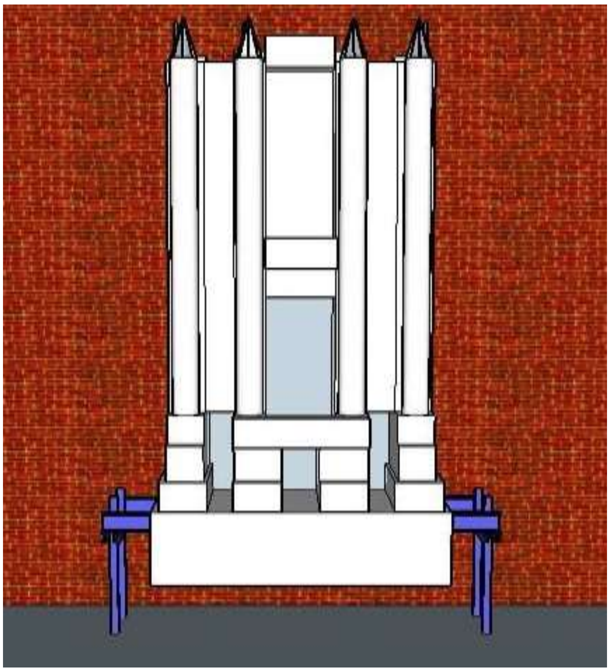

Figure 10: Schematic of the Opera Box immediately after jacking.

Most of the supplementary steelwork designed for the jacking operation was retained, providing increased strength for seismic loads.

4. Chief Post Office

The catalyst for the restoration and strengthening of the Auckland Chief Post Office (CPO) was the construction of the massive Britomart underground railway station. For this project, the CPO was to be the main thoroughfare from Queen Street to the underground linking the trains to the buses and ferries.

Figure 11: Front view of the CPO (2011).

The upper 3 levels were strengthened but not refurbished and leased until a later date. However, the ground floor and basement were both strengthened and modified to become the Britomart Interchange.

The ground floor was originally half a storey above street level with the basement floor half a storey below. In the new configuration, this was changed so that the ground floor was approximately at street level, providing easy pedestrian access to and from the building. A new basement was constructed a full storey below ground with an underpass to the other side of Queen Street.

The challenges for the Contractor with these alterations were:

- Ground water. As the original higher-level basement had already experienced flooding problems, the construction of a deeper basement was even more difficult.
- Careful management of the lateral support systems as the floor slab and basement were demolished around the internal columns.
- Monitoring of the structure and temporary supports whilst sections of the perimeter foundation beam and piles were removed.

One of the major undertakings was to create an opening 20 m wide by 10 m high in the rear brick wall of the building. This was needed to provide a spacious and naturally lit opening for the escalators and stairs from the platforms below.

Figure 12: The new columns & beam in the rear wall.

Temporary support was needed for the opening in the rear wall while the new columns and beam were cast. The trick was to design a support system that would not get in the way of the new work!

Figure 13: Schematic showing the new columns & beam.

The columns were constructed by cutting vertical slots in the wall. This required very little temporary support as the brickwork was able to arch over the relatively narrow slots.

The beam was more challenging, requiring an innovative approach to support the estimated 350 tonnes of floors and walls above. The method used involved casting the beam in two halves with a vertical construction joint. The first half of the beam (the part inside the building) was notched into the wall and cast while most of the brick wall was still in place and still providing a good vertical load path. Steel columns and beams were then fastened to the outside face of the wall so in tandem with the first half of the beam they provided vertical wall support whilst the second half of the beam was cast. The beam was designed with a set of stirrups for its first duty (that of temporary support during construction) and a second set of stirrups for its permanent load cases. The second set of stirrups, fully enclosing the longitudinal bars, consisted of two “C” shaped bars that were site welded to form a closed loop.

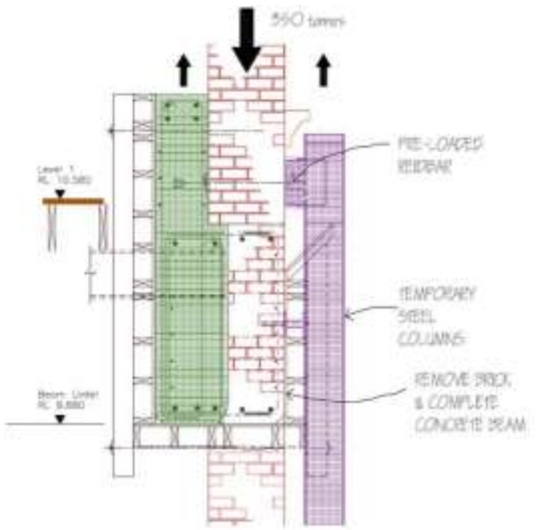

Figure 14: Schematic showing the partly constructed lintel beam in the rear wall of the CPO.

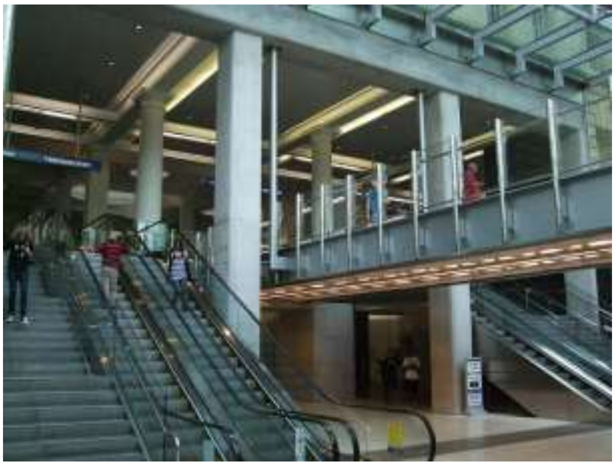

Figure 15: The new columns and beam in the rear wall of the CPO.

A detailed survey of the existing cracks in the wall was carried out and their condition monitored before, during and after the construction of the new columns and beam. No change was observed.

5. Auckland Museum

The Auckland War Memorial Museum was originally built in 1929.

Figure 16: The Auckland War Memorial Museum (2011).

During the restoration and strengthening of the Museum in 2004–2007 new utility and exhibition spaces were constructed. This included underground car parking and a Grand Atrium constructed within the semi-circular courtyard at the rear. This was a challenging task described as constructing a 7-storey building within the confines of a heritage building.

Figure 17: The wave-like roof of the new Grand Atrium is just visible in this photo of the rear of the Museum.

A major challenge for the Contractor was the construction of a truck dock entrance to a new underground loading bay.

Figure 18: The new truck dock entrance.

A section of the perimeter foundation beam had to be removed and new beams cast. Self compacting concrete was used under the existing structure so that full load bearing contact could be achieved. When the concrete for the new beams had hardened, it was post tensioned with high strength stressing wires.

6. Auckland Art Gallery

The Auckland Art Gallery was the oldest of the recently refurbished civic buildings. The original building with the clock tower was built in 1887 and subsequent extensions were constructed in 1913, 1916, 1971 and 1981.

Figure 19: The original building from Kitchener St.

As with many similar buildings, the floors and roof were strengthened with layers of plywood and tied into the perimeter walls to brace the walls for seismic loads.

Figure 20: The original building from Wellesley St.

New electrical, plumbing, air conditioning, fire protection and security systems were installed as part of the upgrade. Some of the more recent additions to the Art Gallery were demolished to make way for a new 5-level extension featuring a glazed atrium.

The refurbished and strengthened Auckland Art Gallery was completed and opened in 2011.

Figure 21: The new glazed atrium extension during construction.

7. Conclusion

The five buildings recently strengthened and refurbished by the Auckland City Council provided some interesting challenges for Contractors. In particular, the refurbishment frequently involved adaptations to improve the buildings' usefulness. These changes required innovation and complex temporary support structures to protect the delicate heritage fabric.

8. Acknowledgements

Much of the information for this paper was researched and published by the author in the book *Evolving Auckland – The City's Engineering Heritage* (Christchurch: Wiley Publications, 2011).

The author acknowledges the assistance of Downer NZ Ltd, Hawkins Construction and the Auckland City Council for help in the preparation of this paper.

THE STRENGTHENING OF HERITAGE BRIDGES – CONSTRUCTION CHALLENGES

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Abstract
Many of the bridges in Christchurch were damaged by the Canterbury earthquakes in 2010 and 2011 and some of these were heritage structures. The task of repairing and strengthening heritage structures presents a number of interesting challenges for the Contractor. Downer NZ Ltd. was the contractor for the repair of three single span heritage bridges across the Avon River in central Christchurch: Armagh Street Bridge, Colombo Street Bridge and Antigua Street Bridge. The authors describe some of the construction challenges encountered in the repair of these bridges.

1. Introduction

The Armagh, Colombo and Antigua Street Bridges were all damaged in the Canterbury earthquakes of 2010 and 2011 by ground movement, including lateral spreading. The repair of these Christchurch City Council (CCC) owned bridges has been the responsibility of the Stronger Christchurch Infrastructure Rebuild Team (SCIRT), an alliance funded by the Christchurch Earthquake Recovery Authority on behalf of the Government, the CCC and the New Zealand Transport Agency. The work is being carried out by five "Delivery Teams": Downer NZ Ltd., City Care, Fletcher, Fulton Hogan and McConnell Dowell.

2. Armagh Street Bridge

Built in 1883 the Armagh Street Bridge is a Category 2 historic place (List No. 1830) on the New Zealand Heritage List/Rārangi Kōrero. It is a road traffic bridge that also carries the inner city tram tracks. The structure is a brick arch with a clear span of 12.2 metres (m), a rise of approximately 2 m and a skew of 16°. The brick arch barrel is 685 millimetres (mm) thick and is supported on unreinforced concrete thrust blocks.

Figure 1: Armagh Street Bridge.

The February 2011 seismic event caused a longitudinal crack in the arch soffit measuring up to 20 mm in width.

The repairs specified included investigation and reporting on the extent of the crack, repairs to the crack itself, refurbishment of the cast iron balustrading and repairs to the footpaths and road surface. Some of the interesting challenges for the Contractor were:

- Creating a dry work area around the foundations in the flood prone area.
- Temporary support for the brick arch during partial removal and reinstatement of bricks in the arch soffit.
- Observing and documenting artefacts and liaising with heritage specialists during the course of the work.

Figure 2: Longitudinal crack in the arch soffit.

Several methods have been used in the past to hold back the water and create a dry working space. These include sheetpiling and water filled inflatable rubber dams. Neither of these methods was suitable for Armagh Street Bridge – there was no headroom to drive sheetpiling and a rubber dam would have been too bulky.

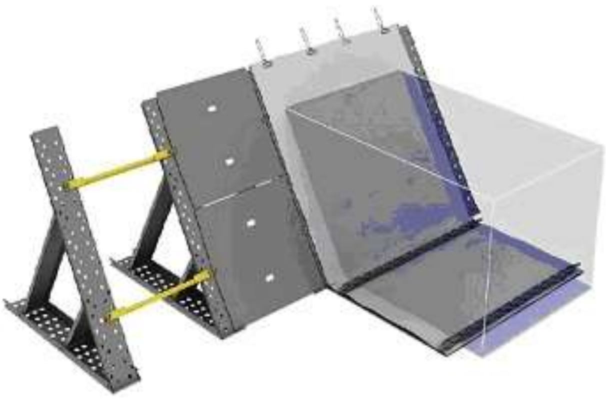

Figure 3: Proprietary A-Frames – courtesy Hydro Response Ltd.

The method used was to erect a set of proprietary steel A-frames supporting aluminium panels to form a wall or dam around the work area. A continuous plastic sheet material was then laid over the panels and secured in place by workers wearing waders. The water isolated in the “working area” side was then pumped out and as this was done, the weight of the water on the “river” side pressed the plastic down, sealing it on to the river bed. It was still necessary to run a small pump in the work area to contend with leakage, but this presented no difficulty.

Figure 4: The Hydro Response dam in place.

There was a flood event during the course of the repair work which overtopped the dam. Work was suspended for two days and the retaining structure reinstated within 4 hours of water returning to normal levels.

To enable work to progress safely under the bridge during brick removal, crack investigation and crack repair, a method of temporary support was required. The challenges for this part of the work included estimating the loads to be supported and configuring props to suit a curved soffit and a sloping riverbed.

Following initial inspections of the structure, it was decided that the temporary works would be designed to support ‘a tonne of bricks’ which may potentially come loose either as rubble or as a block. The work would be regularly monitored by engineers and the load re-assessed if necessary.

An ingenious bearer member was designed to rest on the river bed. This was fabricated from a steel channel section and hinged to a bracket bolted to the abutment. The hinge allowed the bearer to rotate to the angle of the existing river bed and assured a reliable load path. A series of ‘chock plates’ were pre-welded into the channel so that readily available ‘Acrow Props’ could be placed with their bases fitting squarely in the channel and their tops set tangentially to the curved soffit.

Effectively, this provided a series of props to the soffit at spacings of 1.5 m in each direction for the area to be repaired. Removable plywood panels were placed in the spaces between the props so that small areas could be sequentially opened up for repair whilst the remaining areas had temporary supports in place.

Figure 5: The temporary works in place.

The other aspect unique to this project was that of discovery and documentation of archaeological artefacts. Excavations were necessary in the river bed to anchor the temporary works and this activity yielded items, such as pre-1900’s bricks, timber formwork from the original construction, metalwork, a handmade shoe, a coin dated 1889, horseshoes and various pieces of china. Some excavations were also undertaken in the road surface on top of the bridge to inject cracks identified in the top course of brick and also to fill the void beneath the tram tracks. For each discovery, the CCC’s Archaeologist was notified and the item photographed and recorded, noting the date and location of its origin. The records are currently being processed and artefacts studied by Underground Overground Archaeology.

Figure 6: Various artefacts found at the site.

3. Colombo Street Bridge

Built in 1901, the Colombo Street Bridge is another Category 2 historic place (List No. 1835). The 1901 bridge replaced a 9 foot wide brick and timber structure built in 1858. In 1930, the bridge was widened to form the current structure which consists of 12 riveted steel girders supporting a reinforced concrete deck. The widening included the addition of two non-structural steel outer arched girders that were erected to support the cast iron handrails and to improve the bridge aesthetics which reflect the Victorian era.

The unreinforced concrete abutments are founded just 1 m below river bed level and both suffered cracking and rotational movement of up to 30 degrees. This was caused by liquefaction and lateral spreading during the February 2011 earthquake. Further repercussions of this saw the two outer-arch girders and the cast iron handrails on each side of the bridge buckle under the sudden axial load which occurred when the abutments rotated towards each other.

The Contractor was required to:

- Remediate the ground adjacent to each abutment and install inclined anchors from the abutments into the strengthened ground.
- Lift the bridge clear of its abutments, re-build the top part of the abutments, install new bearings and set the bridge back down on the strengthened abutments
- Remove the cast iron handrails, repair off site and reinstate onto the bridge
- Grit blast and paint the outer-arch girders
- Repair cracks and spalls to the abutments and pilasters and re-point the stonework wall to match existing

Figure 7: Warped arch girder prior to grit blast and painting works.

Deep Soil Mixing (DSM) was the method used to stabilise the liquefied ground surrounding the abutments. This involved the installation of a grid of 800 mm diameter concrete columns to varying depths ranging from 4 m to 7 m, forming a mass stabilised block. Initial efforts to install the columns were unsuccessful due to unforseen ground conditions. The obstructions were removed by excavator and this led to some interesting discoveries.

Historical drawings indicated that the wingwalls of the 1901 structure had been removed during the widening of the bridge. This was not the case as can be seen in Figure 8 where the original wingwalls remained in-situ. This effectively precluded the installation of DSM columns in that area.

Figure 8: Original 1901 wingwalls found in-situ.

In addition to the aforementioned discovery, a more significant archaeological find was the unearthing of the remains of the 1858 brickwork wingwalls. Since historical data for this structure was scarce, excavation proceeded with caution so that a qualified archaeologist could conduct an accurate as-built record of the structure.

Figure 9: Emma Clifford of Underground Overground Archaeology Ltd recording as-built dimensions of the 1858 brickwork wingwalls.

Many of the bricks from the historical structure had collapsed inwards and been used as structural fill behind the 1901 abutments. Consequently, a widespread area of obstructions had to be removed prior to continuing with the DSM works.

Remediation of the ground directly beneath the abutments, which could not be accessed by the DSM rig methods, was stabilized by "Jet Grouting". The procedure was to core a 150 mm vertical hole through the abutment between each steel girder. The Jet Grouting equipment was inserted down this hole until it reached a depth of 1 m below the bottom of the abutment, then a 1m diameter grout column was formed. Difficulties arose when the buried brick remains were encountered just 1 to 1.5 m below river bed level – contrary to what was shown on the as-built drawings. This also led to concerns that the high pressure grouting would permeate under the abutment and into the watercourse, contaminating the river. To cater for this possibility, it was decided to create a dammed area between the abutment and the river, providing a controlled decontamination zone.

Figure 10: Hydro Response water dams were also used for Colombo Street Bridge.

An economical and innovative method was adopted to lift the bridge, and support it, so that strengthening work could take place on the abutments. This involved clamping a number of jacking pedestals to the lower part of the concrete abutments. A continuous beam was installed above the row of pedestals so jacks could be placed in the space between the pedestals and the beam to jack the bridge up. The pedestals were fabricated with a widened top portion so a pair of packers could be fitted, one each side of the hydraulic jacks. This allowed the jacks to be removed until the time came to lower the bridge back down on to the abutments.

Figure 11: Jacking the bridge.

Jacking of the bridge was carried out with all seven jacks operated from a panel which could instantly report jack loads and displacements. The jacking was carefully monitored by engineers to ensure that the bridge was raised evenly and that none of the temporary works pedestals were overloaded. Packing members consisting of short heavy walled steel RHS sections were cut to length on the day and welded in place.

An inspection regime was put in place whilst the bridge deck was propped up to monitor the pedestals and the continuous beam. No movement of the temporary works was observed during the course of the repairs despite the vibrations from heavy plant.

Figure 12: Hydraulic lines connecting the synchronised jacking control unit to the jacks shown in Figure 11.

Grit blasting and painting of a historic structure poses many environmental, health and safety and quality threats. This is mainly due to the lead based paint which can become extremely harmful when it becomes airborne during grit blasting.

Figure 13: Shrink wrap encapsulation of bridge.

In order to mitigate the risks associated with lead based paint, a bounded encapsulation of the outer girder was formed using shrink wrap hugged to the scaffolding. This stopped the contaminated garnet from entering the watercourse and allowed for an effective clean up after blasting. An exclusion zone was established around the confines of the encapsulation with only blasting and painting operatives wearing the appropriate safety protection equipment permitted entry.

One of challenges in the repair of historic structures is that of attempting to replicate existing materials which are no longer available. This dilemma was pertinent to the repair of the pilasters and the repointing work required on the stone wall.

Figure 14: Repointing of the Stone Wall.

Topcoat, a specialist coating contractor, were engaged to identify the existing materials and to propose suitable replacements acceptable to the CCC and their Heritage Advisors. The existing material was found to be a lime based plaster and mortar. The evidence for this conclusion was the observation of hairline micro cracks that had self-healed over time, retaining the integrity of the plaster. The plaster used today is based on Ordinary Portland Cement (OPC) and is hard, non-breathable and does not self-heal. The stone wall, repointed as illustrated in Figure 14, benefits from a lime mortar which is more forgiving than OPC and allows the wall to ''move'' minutely and still retain its integrity. Due to the scarcity and substantial lead times for lime based plaster, the contractor formulated an alternative product by mixing quicklime with water. The water was sat an inch or so above the quicklime to eradicate exposure to carbon dioxide and left to cure for a minimum of six weeks

Figure 15: Rendering of repaired pilaster corner spall.

The final challenge was to colour match the repaired cracks and spalls to the existing fabric. Yellow oxide was used at a reduced dose of half a teaspoon per kilogram of putty as today's oxides are five times more potent than those available in 1930.

Unfortunately, the immediate visual appearance of the new rendering is different to that of the existing. However, it is expected that the colour of the lime putty will fade over time and together with age and moss growth, the contrast will gradually become less apparent. In time, it is hoped that the repair work will blend seamlessly with the existing fabric and to aid with the aging process, a milk spray was applied at all rendered locations to encourage the growth of microorganisms.

Repair works were completed in 2014 with the tilted piers and buckled side girders left in their deformed shape as a reminder of the earthquakes.

Figure 16: The buckled side girders were retained.

4. Antigua Street Footbridge

Built in 1901, the Antigua Street Footbridge was damaged in the 2011 earthquake when lateral spreading caused the concrete abutments to rotate and move towards each other. The bridge is adjacent to the Category 1 historic place Antigua Boat Sheds.

Figure17: Antigua Street Footbridge.

The bridge consisted of a pair of trusses fabricated from rolled steel (or possibly wrought iron) angle and tee section members. The two trusses were braced together and anchored into the concrete abutments. The structure had a timber deck and timber handrails. Lateral spreading forced the two abutments towards each other, causing the trusses to hog in the centre by approximately 400 mm. Furthermore, the structure had fallen into a state of disrepair prior to the earthquake and several of the riveted joints and members had rusted and failed either before or during the earthquake.

The specified repair works included:

- Removal and refurbishment of the steel structure
- Demolition of the existing abutments and construction of new abutments
- Re-installation of the steel structure with a new precast concrete deck.

Work is still underway (as at September 2014) with the steel structure removed and the new abutments under construction.

A major challenge for the Contractor was the safe removal and transportation of the earthquake damaged steel framework. The approach taken by Downer for this work was as follows:

- Remove all of the existing timber deck and any other superimposed loads such as services (pipes and cables)
- Undertake a detailed inspection of the damaged structure along with a review of the SCIRT designer's reports
- Investigate possible crane lifting positions and crane setup locations for the site
- Analyse the member forces under the proposed lifting arrangement
- Finalise the method and execute the lift.

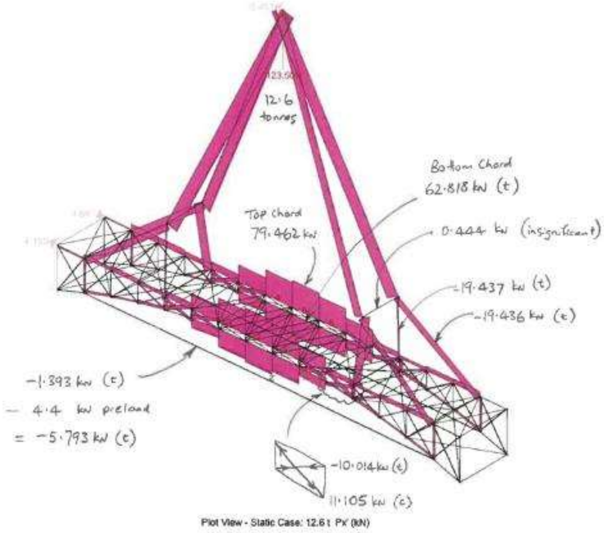

Figure 18: Analysis of the lift using "Multiframe."

A 350 tonne crane was set up on the south bank of the Avon River, as well as rigging for the lift. The design called for installation of a pair of bowstring chords for each truss, with a load cell connected to each bowstring.

Both top and bottom chords were encased in the concrete abutments and it was initially thought that both would need to be cut to remove the bridge.

Figure 19: The crane was set up on the South bank.

Prior to removal, however, it was found that the concrete could easily be broken away from the top chords allowing them to be removed intact.

Final gas cutting of the bottom chords commenced when the crane and rigging were set up for the lift. As cutting commenced, the bridge attempted to straighten from the pre-camber induced by the earthquake.

Figure 20: Cutting the bottom chord & diagonal braces.

The removal of the bridge from its abutments was thus carried out incrementally with careful monitoring and gradual release of the tension in the bowstrings. Small bites of steel were cut from the bottom chords as the remainder of the structure straightened itself, gradually relieving the built-up forces.

Figure 21: Successful lifting out of the bridge. Note the bowstring wires with tirfor and load cell.

5. Conclusions

A number of bridges across the Avon River in Christchurch were damaged in the Canterbury earthquakes and they are currently being repaired by the SCIRT alliance.

Due to their heritage nature, the bridges described in this paper presented a number of interesting challenges for the Contractor. These included:

- Repairing a brick arch soffit on Armagh Street Bridge. Temporary support was provided by a series of radial props.
- Jacking up Colombo Street Bridge to retro-fit new bearings and abutment concrete. The entire bridge had to be supported on steel members that had to be small enough to carry in and install by hand.
- Lifting out Antigua Street Footbridge in one piece for repairs and refurbishment. A detailed analysis of the structure was carried out and care was needed to safely relieve the build-up of forces.

All work was carried out with the involvement and advice of heritage specialists from the Christchurch City Council. Constant vigilance was needed, especially during excavations, so that discoveries of archaeological significance were identified, preserved and documented.

6. Acknowledgements

The authors acknowledge the assistance of SCIRT and Downer NZ Ltd. for help in the preparation of this paper.

TUAPEKA MOUTH FERRY: TAKING HERITAGE INTO THE FUTURE

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Abstract

The paper outlines the history of the Tuapeka Mouth Ferry (also known as the Tuapeka Punt) from its establishment in 1895 to the present day operation, including conditions in the area at the time of its planning and construction and operating incidents. The paper also details council and local settler petitions and operation disputes, design modifications, and accidents. The paper is supported by photographs covering various aspects of the punt's operation over its life to the present day.

1. Introduction

The iconic Tuapeka Mouth Ferry is one of New Zealand's national treasures - the last current driven public ferry (punt) operating in the Southern Hemisphere.

The ferry carries vehicles, cyclists and passengers across the mighty Clutha River near Tuapeka Mouth, a small township in the picturesque Clutha Valley. The ferry has been in continual use since 1896, although service has sometimes been affected and interrupted by river levels, wind, or maintenance.

Early in the history of European settlement the Clutha River was crossed by rowboats, however community agitation saw a public ferry service established near Tuapeka Mouth.

Known locally as 'The Punt', the original vessel had wooden pontoon hulls. This was replaced in 1915 by a larger steel hulled punt that previously operated on the Waiau River in Southland. It was shipped up the Clutha River to its present site, by paddle-steamer.

Figure 1: Paddlesteamer "Matau" (1882-1901) passing the Tuapeka Mouth Ferry on the Clutha River (from the Frank Leckie collection).

To control the ferry, two heavy wire cables across the river (one upstream and one downstream) are permanently attached, and the craft is powered across the river solely by water pressure against the hulls. The direction is dictated by the rudders setting which directs the hulls at an angle against the river's current. This historic ferry generally crosses the 130 metre (m) width of the river in about four minutes.

Figure 2: Clutha district council map (black spot denoting punt location).

Figure 3: View from mill hill Clutha valley with punt in distance (Photo by John McGowan).

The Punt has been used to carry livestock and farm equipment, horses, gigs, and wagons.
However, today it usually carries cars, other motorized road vehicles, cyclists and pedestrians.

This paper outlines the history of the Punt from its early installation and operation up to the present day. It remains an important part of the local road network, is owned by the Clutha District Council (and part funded by the New Zealand Transport Agency), and is operated by the Clutha District Council's Roading Maintenance Contractor.

2. History of the Tuapeka Mouth Ferry [1]

By repute, the first ferry at Tuapeka Mouth was a privately-owned whaleboat in use from about 1871. Records show that as early as January 1862 J. Lowe wrote to the Provincial Government requesting permission to build a ferry house at the junction of the Tuapeka and Molyneux Rivers, which indicates the existence of a ferry. [2] It was some 20 years after the abolition of the provinces, however, before settlers petitioned the Tuapeka County Council (TCC) for a public ferry. [3]

Figure 4: The original puntmans cottage (South Otago Museum collection).

After some debate over funding, TCC became the major backer of the project, with a Government subsidy and a minimum of support from Clutha County (the river forming the boundary between the two counties). Tenders were called in August 1895, and the building contract was let to Tyson and Dunlop for £333. Service officially started on February 22 1896. [4 and 5]

To make the punt self-supporting TCC secured support for a toll, at the same time introducing similar rates for its other punts. Users of the nearby Rongahere punt were not pleased, as there had previously been no charge for that ferry. Initial rates at Tuapeka Mouth were: passengers, 6d; horses, 6d; cattle, 3d; sheep, 20 or less, 1d; 20-200, 1/2d; over 200, 1/4d. [6] Reporting the opening of the punt, the *Otago Witness* remarked that at 6d a horse the benefits of the ferry were doubtful: “Why should ratepayers pay for what is free at Millers Flat?” [7]

Bill Buchan, the first puntman, reported that in the initial monthly period (22 February–22 March), 336 passengers and 255 horses crossed over. [8] By 1901, a six-month tally gave these figures: Tuapeka to Clutha - 984 persons, 751 horses, 149 vehicles, 200 sheep; Clutha to Tuapeka - 918 persons, 689 horses, 104 vehicles, 425 sheep. [9]

Figure 5: Commemorative plaque (Photo by Roger Hodgkinson).

In 1900 the TCC asked the Government to give it control of the punt with authority to charge half the cost of past and future maintenance to Clutha County. But Clutha had consistently opposed the Tuapeka Mouth punt, since it operated the Clydevale punt only 11 kilometres (km) downstream. The Rongahere punt was only 3.2 km upstream, so Clutha declined to contribute to Tuapeka Mouth costs and maintenance. However, it offered some used wire rope, the plans of the Clydevale punt and the services of its engineer.

The Chief Surveyor of the Lands and Survey Department headed an inquiry at the Tuapeka County Chambers, Lawrence, into the liability of the two councils and Clutha felt vindicated when it was decided to divide the costs in the proportion: Tuapeka County 85% and Clutha County 15%. In 1902 the punt was officially vested in the Tuapeka County Council. [10] However, a 50/50 division was agreed to in 1907, with effect from January 1908, and after the age of the motor vehicle arrived the Government subsidy was replaced with annual subsidies from the Main Highways Board and later, the National Roads Board. [11]

Figure 6: High side configuration for cattle (Tuapeka Mouth Ferry, Neg E1332/8 Hocken Collections University of Otago Library).

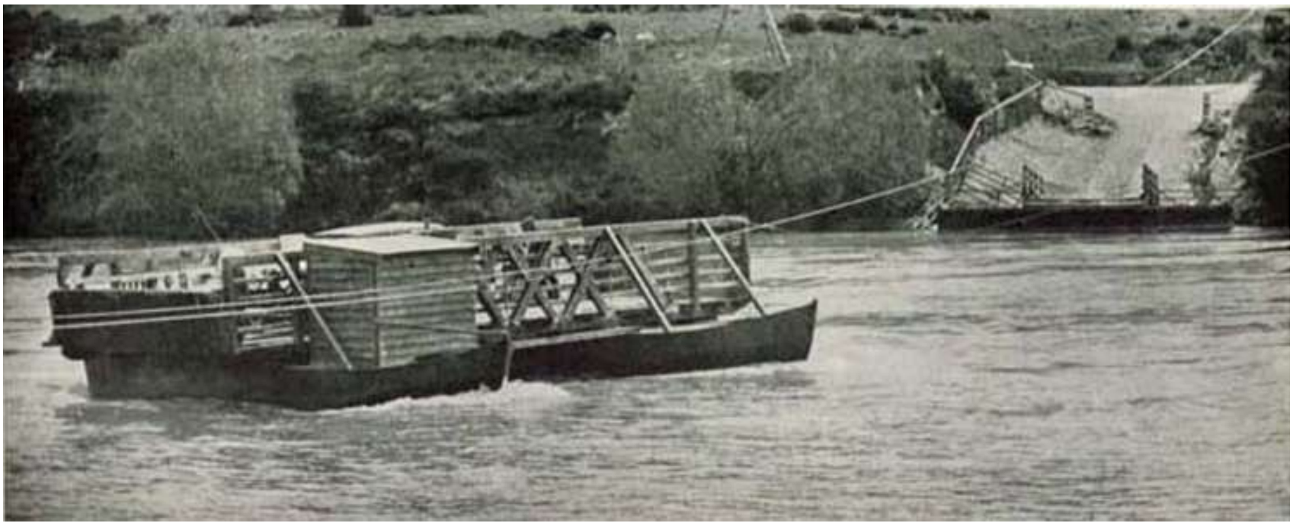

Figure 7: The Ferry Pontoon at Tuapeka Mouth: Type of crossing which is fast disappearing in New Zealand (Otago Witness).

Throughout its operation the Tuapeka Mouth punt was a platform on two boats, but improvements were made from time to time. Major repairs were carried out in 1908 and in about 1915 the boats were enlarged and the decking lengthened. This was described as a 'patch-up' job, as the punt was old and ready for replacement. [12] With the opening in February 1915 of a bridge over the Waiau River at Tuatapere, the punt there became available, and over a three-month period it was dismantled by John Smith (the Clutha County foreman), railed to Balclutha, and taken by river steamer to Tuapeka Mouth. [13 and 14]

The new punt was larger than the one it replaced, being equipped with twin iron-hulled boats, and when it came into service in late 1915 it was a considerable improvement. The punt in use today is substantially the craft introduced in 1915, and Marine Department certificates ensure safety standards are maintained. In a major overhaul in the late 1980s, new runners, new sides and new decking of Indian jarrah replaced older fittings. [15] For a time the punt operated with an engine and propeller, installed in 1940 or 1941 from the Clutha County's Paretai punt, but for some reason the engine was later taken out.

Problems have led to occasional strife between residents and the County authority. In May 1928 they complained of irregular and unreliable operation of the ferry, disruptions being caused by river and wind conditions. [16] The locals, of course, wanted a bridge, but were not given one. From 1945 there was an almost constant struggle between Council and residents who, if they couldn't get their bridge, certainly demanded retention of the punt. In 1945 the Council set up a subcommittee to press for replacement of the punt and upgrading of the road via Rongahere to Beaumont. The Tuapeka Mouth Progressive League, which convened a public meeting in early 1946, presented substantial reasons for a permanent crossing.

Figure 8: In transit (Punt on Clutha, Tuapeka Mouth, c/nE3537/35 Hocken Collections University of Otago Library).

The resignation of puntman Whitty led to a closure of the service from 1 February 1947. A deputation and petition to the Council followed, and the punt was restored to service with a temporary puntman until a contractor was found to undertake its operation. The suspension of the service in 1948 caused residents again to suspect imminent closure, but a low river and serious shoaling had been the problem. [17] Weekly saledays at Tuapeka Mouth had been the busiest times for the punt and the ending of the sales in the late 1940s greatly reduced patronage. [18]

Apart from a few test bores, no progress was made towards a bridge and in May 1956 the punt was closed for some time for extensive repairs. Only then would the Marine Department renew its certificate. [19]

When Bill Small was puntman, the punt broke away a short distance with the mail bus, Dave Cross and Richie Crawford on board. The river was low, the punt scraped too hard, and while the ropes held, the sheerlegs on the bank gave way. Graham Geddes arrived with his tractor and Jack May of Clydevale rowed out with a rope, but on the first attempt to winch the punt back the rope broke. A second attempt succeeded.

In the 1950s, Bill Small's time as puntman, the punt operated seven days a week, 7am to 7pm, with an after-hours charge of 2s 6d. His pay under contract with the TCC was £1 a day, and he only had Saturdays off. Besides the mail bus, there was a steady flow of traffic to and from the Tuapeka Mouth garage, and the storekeeper made deliveries to Wharetoa. For a time heavy trucks unloaded their freight on one side of the river and reloaded on the other, but later they stopped using the punt altogether.

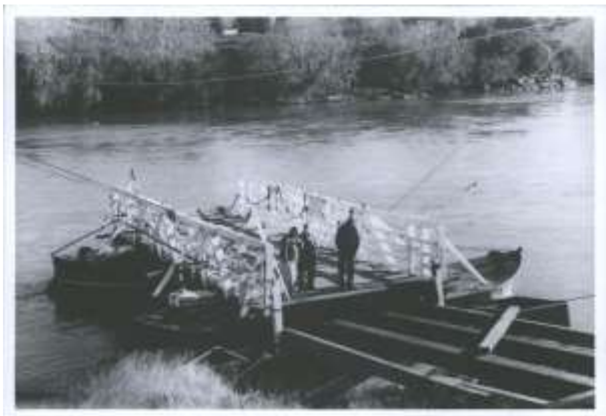

Figure 9: Tuapeka mouth punt after Tuapeka County workmen removed jetty planking, June 1966, Ministry of Works Dunedin (Hocken Collections University of Otago Library.

In September 1960 steel decking was installed on the punt-boats and life rafts provided, but a decade of peace was broken in 1966 by a debate over the condition of the punthouse, which had been occupied by both Small and his successor, WE Gray, (Bill Gray, incidentally, earned the nickname 'the Admiral' after he was given a handsome yachting hat by a grateful American). [20] Tuapeka doubted that Clutha County would wish to share the cost of a new house, but Clutha authorised limited repairs and said it wished the punt to be retained, An annual review of the position was to follow.

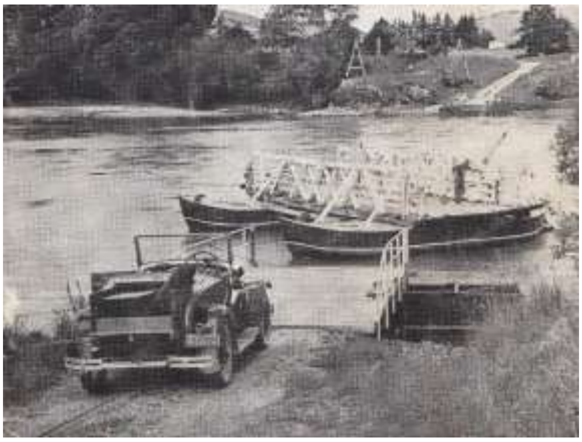

Figure 10: Waiting for the Tuapeka Mouth punt to moor at the landing stage c.1964 [Courtesy Maureen Finch, Waihola]

The sudden resignation of the puntman, however, led to a confused situation with County workmen starting to dismantle the staging early on 3 June. Car-loads of residents gathered and about 60 quickly convened a meeting, set up a committee, and made representations to all those in authority. There was some delight when the workmen grounded the ferry in midstream. But it transpired that the Tuapeka County Chairman and Clerk had merely decided to remove the staging to prevent unauthorised use of the ferry in the absence of an operator. The next development was that the chairmen of the two Councils announced that minor repairs would be made to the punthouse and tenders were called for the operation of the service. If these were uneconomic local ratepayers would be consulted. However, the tender of W.E. Gray was accepted and the service resumed on 3 October, with the tenderer providing his own accommodation. [21] The punt-house, incidentally, was later destroyed by fire.

River conditions have not always been kind - if the river was high or low the punt was in difficulty. Early goldminers dredging upstream created a gravel-bar, and later the Roxburgh power station affected water levels and the gravel deposits. When the river is low there may be insufficient current to drive it, or it may ground in shallow water, while the loading and unloading angles to the stages become too steep. [22] In August 1978, when Tuapeka and Clutha County representatives came to see the problem for themselves, they too were marooned midstream for 2.5 hours as a result of the low river level. Yet six weeks later a flood submerged the jetty and access slope, the water level reached the door of the puntman's house, and the punt was pulled up on to the road near the shed. [23] Floods or high wind made it difficult to work the punt away from the Wharetoa bank, though provision of a handwinch and a wire rope attached to the cable downstream of the ferry helped with the problem. By the 1990s the hand-winch was no longer in use.

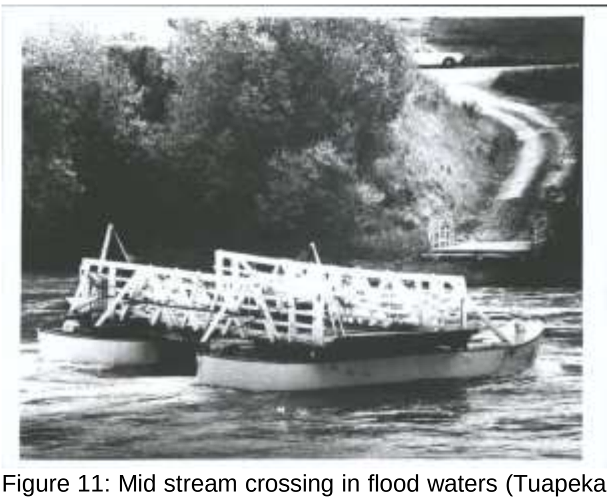

Figure 11: Mid stream crossing in flood waters (Tuapeka Mouth, c/nE5792/20 Hocken Collections University of Otago Library)

C.F. Lucas recalled that the punts:

> …were a most unsatisfactory way of crossing this huge river, as often one would get over all right in the morning and not be able to get back at night owing to the wind, and many a night I have waited at the Tuapeka Mouth punt in the pouring rain for a couple of hours, and then the puntman would yell out that he was going to bed as there was no chance of crossing that night as he couldn't get the punt out. I would then get on my horse and ride up to the Rongahere punt which was much more sheltered and usually got over there. This meant an extra twelve miles ride. [24]

Even the puntman could be stranded by high wind, which also affected settlers and stock, and delayed the mail. From time to time the Roxburgh dam authorities would advise they were about to release an accumulation of logs. At such times service was suspended and the punt was moored on the Rongahere side. [25]

In the ferry's long years of operations it was inevitable that there should be a number of accidents.

On 11 March 1913 Annie Bennie and her brother William were crossing in a gig on a cold, wet night when their horse backed off the punt, taking Annie and the gig with it. William and puntman Nehoff gave chase in the punt's boat and rescued her about 1.5 km downstream. Miss Bennie sustained a broken collarbone, bruising and shock. The horse and remains of the gig were found stranded at Cox's Landing. Nehoff was given a presentation for his gallant rescue and the TCC engineer was instructed to supply the punt with strong gates and impose rules for closing them. [26]

It was at 2.25 pm on 20 May 1928 that John and Mary Fahey drove for the first time onto the ferry, their Chevrolet failed to stop and they plunged into the river. The puntman used his boat and threw a rope to rescue John, but Mrs Fahey, dragged down by a fur coat, drowned. As a result two circular lifebuoys were bought and the coroner's jury expressed the opinion that in future the tailboards should be fully raised when vehicles of any kind were being conveyed across the river. [27] This, incidentally, was a period of heavy usage. In the 13 weeks ended 30 June 1928, the tally was: motorcars 1149, motor trucks 154, motor-cycles 241, bicycles 529, horses and riders 631, horses and gigs 218, sheep 6505, cattle 33, horses 78, horse wagons 22, horse drays 124, sleighs 9. [28]

On 24 October 1931, two vehicles were on the punt - blacksmith Archie McCorkindale's car and Mrs Latimer, the puntman's wife, with her horse and gig. As the punt neared the staging McCorkindale cranked up his car, forgetting he had left it in reverse gear, and it shot backwards, pushing horse and gig into the river. Mrs Latimer, clinging to the railing, was very fortunate not to be swept overboard. The gig was lost and the horse died two days later. Again operating changes were imposed: tail-gates to be raised to the vertical, chains to be in place 3 foot 6 inches above the deck, and a sign placed warning motorists to disengage the gear of their vehicles. [29]

Figure 12: Tuapeka Punt operator Peter Dickson, with his dog Mission (7), has been ferrying people and cars across the Clutha River for 16 years. Photo by Rachel Taylor.

Four years later, in October 1935, 10-year-old Rita Muirhead and her bicycle plunged off the staging while she was attempting to board the punt before it had reached the jetty. She was hauled out with the aid of a gaff. [30]

In 1943, Gerald James of Rongahere parked his grey V8 coupe at the top of the rise while he waited for the punt to arrive. Apparently as a result of brake failure, the car coasted down the slope, crossed the jetty and plunged into the river beneath the approaching punt. It was recovered the next day, the only damage being from water and silt. [31]

On 20 October 1986 George Johnston, his wife and a passenger were in a car which slowly approached the punt from the Tuapeka Mouth side. However, at the last moment, and before the loading flap could be raised, the car suddenly lurched across the deck and into the river. Fortunately it floated long enough to ground on a submerged rock, where the occupants opened the front doors and stood beside it amid the waters of a rapidly rising river. In the township the Whaarua Craft Shop was open and there were quite a number of people about. Rescuers floated a dinghy out on a rope from the punt, the three being plucked one by one from a very precarious situation. On being checked their car was found to have had a mechanical fault. [32]

More recently, 27 November 1994, a minor mishap resulted in a member of a television crew sustaining a broken arm as a result of the punt striking one of the landing stages with more than usual force. [33]

In the big flood of 1978 the punt slipped from its moorings, broke the chain and shot across the river before being recovered by Lloyd Thompson. When this flood washed out the Clydevale bridge approaches and closed the bridge, traffic was diverted for some time via Tuapeka Mouth. [34]

Ron Dodds recalled that when he was appointed puntman the ferry had an auxiliary motor for emergency use, but it was removed during his time and not replaced. [35]

Once while the punt was closed awaiting the appointment of a new puntman, a resident joked of urgently having to retrieve honey from his bees on the Rongahere side. He and a mate took their tractor and trailer across on the punt, did the job, and quietly returned without any bother. Nor were they the only ones.

For a short period the punt had a one-armed puntman. R. Sell had lost an arm below the elbow, but despite that handicap he took charge briefly in 1977. [36]

A list of puntmen over the years is:

- W.G. Buchan, 1896–1900
- W. (Bill) Nehoff, 1900–1924
- W. (Bill) Latimer, 1924–1945
- W.S. Whitty, 1945–1946
- D.A. Houliston, 1947–1950
- W.H.J. (Bill) Small, 1950–1958
- W.E. (Bill) Gray, 1958–1975
- E.R. Tallentire, 1975–1977
- R. Sell, 1977
- R. McGowan, 1977
- Ron Dodds, 1977–1984
- L. Thompson, 1984–1994
- Peter J. Dickson, 1994 to present. [37]

Since the local body amalgamation in 1989, the controlling authority for the punt has become the Clutha District Council. These days the punt is most easily handled in the earlier part of the morning or in the late afternoon. This is when the river is high as a result of water being released from the Roxburgh power station. By midday, when the river is often low, the punt risks becoming stranded. The visitors' book records many overseas and New Zealand tourists whose remarks reflect enthusiasm for a unique experience. Local residents still use the punt regularly, especially customers using the garage, but no stock is carried and the high cattle railings were removed when the district sales ended.

The Otago regional committee of the New Zealand Historic Places Trust took a keen interest in the punt from the 1970s and, although there was a brief technical debate whether the punt was a vessel (which did not come within the Trust's activities) or an installation (which did), it was soon agreed that New Zealand's last public punt was certainly an historic feature that deserved preservation. It was added to the New Zealand Heritage List/Rārangi Kōrero as a Category 1 historic place in February 2013 (List No. 9599). Special interest groups, such as motor-cycle and vintage clubs, also include the punt in their itineraries, and it still holds a warm place in the affections and interests of the district.

2.1. Picnic at the punt (commemorating 115 years of operation)

Figure 13: 115 year commemoration picnic event and vintage car rally at the punt. 26 February, 2012 (photo by Murray Service).

The commemoration picnic in 2012 was attended by locals and other interested persons from all over New Zealand. The event included continuous crossings on the punt with vintage cars and motorcycle groups taking advantage of the punt crossing experience. A school bus and class of school children also took the punt from the Rongahere side to attend the picnic. Side shows and arts and craft exhibitions were set up at the nearby showgrounds and the history of the punt and the area, including early gold field memorabilia, were on show at the adjacent school hall. Bill and Murray Service, grandsons of John Smith, the Clutha County foreman involved in bringing the punt from the Waiau River at Tuatapere to Tuapeka Mouth, also attended and set up a linear turbine being developed by Murray Service below the punt landing.

Figure 14: Punt in all its glory. Picnic at the punt 26 February, 2012 (photo by John McGowan).

2.2. Tuapeka Turbine [38]

The Tuapeka turbine was inspired by the Tuapeka punt and operates on a similar principle. Vanes are suspended from a cable/chain and are turned to an angle to the river flow (similar to turning the punt at an angle to the flow). The vanes are thus driven to move sideways across the river pulling the cable/chain which moves in a loop and rotates wheels at each end of the loop to generate power or pump water. This turbine has the advantage in that it can be installed across slow flowing rivers, such as the Clutha at Tuapeka Mouth, to harness the low head energy flow. The turbine is still in early development, and is currently the subject of a final year engineering project at Auckland University. [39]

Figure 15: Murray and Bill Service with Tuapeka turbine at the punt picnic 26 February, 2012 (photo by Shu Hashimoto)

3. Conclusion

The Tuapeka Mouth Ferry has special significance not only due to the longevity of its service to the local community but because its water motive power technique may inform present day exploration and experimentation in utilising water power. Murray Service is undertaking such work in New Zealand, in pursuit of economical electrical water generation units for isolated communities here and around the world. The Tuapeka Mouth Ferry may in future serve as an available and useful test bed for future river turbines.

This important heritage item may well help us to make valuable advancements in harnessing our water resources into the future. This humble workhorse of a Ferry will continue to be a tourist attraction and enable people to experience a tranquil ride across the picturesque Clutha River.

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4. Acknowledgements

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[23] *Clutha Leader*, Aug. 11 1978; Ron Dodds

[24] Lucas, *ibid*, p.38.

[25] Ron Dodds.

[26] *Tuapeka Times*, Mar. 15 1913 p.3.

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HIDING IN WELLINGTON – NEW ZEALAND'S FIRST HOLLOW CONCRETE BLOCK BUILDINGS

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Abstract
The modern hollow concrete block dates from 1900, when Harmon S. Palmer of USA patented firstly the machine and then a block system. By 1904 the first New Zealand business to use Palmer's block was in operation. They built part of a warehouse (since demolished), three houses and one retaining wall – all of which are still in existence. The company went into liquidation in 1906 and had been forgotten. The paper traces the introduction of the hollow concrete block to NZ and its early Wellington use, concluding the New Zealand Hollow Concrete Block Company laid the foundations for the future hollow concrete block industry.

1. Introduction

Pre-cast concrete blocks date at least from the 1830s [1], with 'cast-stone' (the use of concrete as substitute for natural stone) in use from the late 1860s [2].

William Newsham Blair's 1879 book 'Building Materials of Otago' recorded that in England solid concrete blocks were "*manufactured in large quantities by machinery and form excellent building material"* with a "*common mixture being one part cement to six parts sand*". Blair also reported that moulded blocks "*for arch-stones, quoins, sills, lintels, steps and mouldings of all kind"* were "*laid like stones or brick*". The alternative to solid concrete blocks is the "*monolithic system"* which "*consists in laying the soft ingredient between frames in the position they are ultimately intended to occupy"*, but concludes it is not as good as blocks as there is the risk of faulty materials, but that it "*is much cheaper, and on that account is more generally adopted*" [3]. The historic origins of the two systems are different as monolithic (more recently reinforced) concrete comes from the tradition of pisé, or rammed earth, while pre-cast blocks are from the masonry, or even adobe, tradition [4].

Pre-casting had the advantage of allowing the components, and possibly the entire structure, to be prepared at a suitable site for later transport to their final location. Solid concrete blocks had an obvious disadvantage – weight. A solid block measuring 12 inches (in) x 9 in x 32 in (30 centimetres (cm) x 23 cm x 81 cm) could weigh 180 pounds (82 kilograms), making it beyond the capacity of one man to lift and requiring the use of hand-cranked derricks or cranes [5]. The most obvious way to reduce the weight was to reduce the amount of concrete.

This paper will briefly outline the invention of the hollow concrete block, its arrival in New Zealand and the earliest business to make use of it. The legacy is in the form of three houses and one retaining wall, which will be described.

2. Hollow Concrete Blocks

The earliest patent referring to hollow concrete blocks was awarded to Joseph Gibbs in 1850 (British Patent 13,071) while C S Hutchinson was awarded the first United States of America (US) Patent (53,004) in 1866. In both countries other patents followed [6]. Simpson argues that none of these early patents led to the widespread production of concrete block. It was not until Harmon S Palmer had experimented for ten years, including building six houses in Chicago in 1897, that he brought together manufacture and design patents that led to the creation of the modern hollow concrete block [7].

2.1.1. Harmon S Palmer's Patents

Palmer's first patent was in 1887 for a "*Machine for Molding Building Blocks"* (patent 375,377) which produced a solid concrete block [8]. This machine introduced the combination of removable bottom plate, a vertically moving core-block with a spur-pinion mechanism and hinged end-plates. Palmer's next patent in 1899 was for a "*Machine for Molding Hollow Concrete Building Blocks"* (623,686) [9]. This second machine, which from the drawings and descriptions was probably made of cast-iron, had a tapering core and a mechanism which slightly withdrew the core before releasing the sides.

When coupled with his 1901 patent 674,874 (filed on 21 March 1900, issued 28 May 1901) for a "*Concrete Wall for Buildings*" (Figure 1), it provided the impetus needed to create a widely usable concrete construction system. The object of Palmer's block was to "*simplify, cheapen, and to produce stronger buildings as well as more efficient in protecting from the elements"*. The cavity created "*a thin wall of stone ... to receive the rain ... that a few hours of sunshine will remove all dampness, leaving the walls dry and the* *building in a sanitary and healthy condition"*. The cavities could also be used "*as a ventilator, which can be connected with every room in the house, thereby securing a circulation of air of the most desirable kind"* [10].

Palmer's 1901 patent included designs for a range of blocks, including with notches or "*receptacles to receive the floor-joists and a bottom on which the joists rest"* to permit the use of suspended floors, as well as a specialist chimney or pilaster block. The corner block is of particular interest, as it has a long side (full block length) and a short side (half block length), as shown in Figure 1. This block firstly creates a corner without any joint and secondly provides for a perfect bond for the next course merely by being reversed.

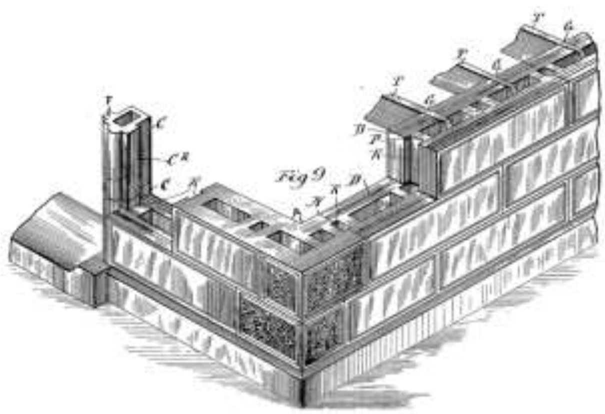

Figure 1: US Patent 674,874 Concrete Wall For Buildings – Figure 9. 28 May 1901.

Palmer continued to develop the machine to improve its performance, patenting a total of 7 versions of increasing sophistication and intricacy.

2.2. New Zealand Hollow Concrete Block Co.

Previous research has suggested that hollow concrete blocks were not used in New Zealand until 1909 [11] or 1910 [12]. In fact it took under three years for the patent for Palmer's hollow concrete blocks to reach New Zealand, with provisional New Zealand patent 17,649 issued on 11 March 1904 for "*A new or improved construction of stone or blocks for building purposes*." This patent was issued to *"Niels Nielsen of Maranui, Wellington, New Zealand, Builder and George Atkinson, of Wellington aforesaid, Carpenter (nominees of Harmon S. Palmer, of 1401, Binney Street, Washington, United States of America, Inventor)"* [13].

This patent application was abandoned (complete specification not filed) at some time between 22 December 1904 and 11 January 1905 [14], so the file is not held by Archives New Zealand.

Just under a year later, on 5 February 1905, application was made by Niels Nielsen, again as nominee for the Harmon S Palmer Hollow Concrete Building Block Company, for an '*Improved machine for moulding hollow concrete building blocks'* [15]. The New Zealand patent text is identical to Palmer's US Patent 727,427 issued on 5 May 1903 [16], including the American spelling of 'mold', except for a minor change in wording in the introduction to the list of claims. The illustrations are identical, although redrawn. This became New Zealand Patent 19,038, gazetted two years later on 18 May 1905 [17].

Little is known of the origins of Niels Nielsen. According to his naturalisation papers he was born in "Danmark", had arrived in New Zealand in 1896 and in 1899 was 26 years of age [18]. The signature on the naturalisation paper matches that on his application for patent 18,666 [19].

Even less is known of how Nielsen learnt about Palmer's machine, how contact was made with Palmer's company or how he obtained the right to patent the machine in New Zealand. No information has been found on other aspects of Nielsen's life or death.

2.2.1. Promoting Hollow Concrete Blocks

On 7 June 1904 Niels Nielsen (sometimes spelt Neils Neilsen) started newspaper advertisements promoting buildings that were '*Draught-proof, Damp-proof, well Ventilated, and to last hundreds of years.'* [20]. The same advertisement continued until 27 June 1904. For the advertisement on 28 June 1904, Nielsen's name had been replaced by that of the Wellington Hollow Building Block Co.

In his advertisement of 10 August 1904 Nielsen invited inspection of '*Ahradson and Son's Furniture Warehouse, No. 30, Tory-street, part of which has been erected by the Wellington Hollow Concrete Building Block* Company' [21] (this building has since been demolished), and by 20 October 1904 that those '*who want a substantial, durable and cheap house*' could see the factory and '*completed houses*' in Lyall Bay [22].

Following the same practice as early North American block makers [23], Nielsen also actively promoted hollow concrete blocks behind the scenes. On 15 June 1904 he wrote to the Wellington City Council (WCC) requesting the building byelaw be amended to allow concrete block walls to be thinner than a wall made of conventional bricks. He argued that the blocks, made of four parts sand to one cement, had been tested to stand a pressure of 1270 pounds per square inch (184 kilopascals) and had the appearance on the outside of natural stone [24]. The Wellington City Engineer was not in favour, providing advice that if "*a company wishes to have their blocks used in two storied buildings their proper course is to have a machine capable of turning out the extra thickness*" [25], and this view prevailed.

Nielsen's letter to the WCC [26] included an advertisement (most likely modified in Nielsen's own hand) from "*Harmon S Palmer Hollow Concrete Building Block Co, Washington D.C. - Revolution in Building Methods*", which had an illustration which closely followed that in the 1901 patent (Figure 1) but showing only rock faced blocks. This illustration was later used for the front page of the company prospectus [27].

2.2.2. Wellington Hollow Concrete Block Co. Ltd.
With business expanding, the Wellington Hollow Concrete Block Company (later the New Zealand Hollow Concrete Block Company) issued a public prospectus on 14 October 1904. Shares were allocated to Nielsen for land, stocks, machinery, plant and goodwill. The prospectus used the construction in Philadelphia of over 6,000 houses a year to illustrate "*the great strides Hollow Concrete Building Block construction is making*" [28].

The prospectus reported an estimated 160,000 cubic yards (122,330 metres cubed) of sand on the 15 acre 23 perches (6.1 hectares) Lyall Bay site [29].

The prospectus was clear on the benefits of hollow concrete blocks. The '*cost of erection is about 15% to 20% cheaper than brick and only 5% dearer than wood*' as well as benefiting from a saving of 60% to 70% in fire insurance premiums compared to wood structures. The selling price was fixed at 2s 3d per block (equivalent to NZ$19 in early 2014, using the Reserve Bank of NZ inflation calculator www.rbnz.govt.nz), compared to 2014 retail price of about $4.50.

The daily budget included two machines each making 150 blocks a day when supported by a motorised mixing machine and five labourers, with additional financial benefits coming from the land being made available for housing through the removal of sand. Based on 275 working days per year (5.5 days a week, 50 weeks per year) a gross annual profit of £4,681 5s 0d was expected [30].

This production rate compares to US rates of 100 per machine per day for 24 x 8 x 8 in blocks [31] and 150 per machine per day [32]. No market price lists for building materials were published in the contemporary Wellington papers, but the 12s 4d per barrel is lower than the cement market prices in Dunedin of 13s 6d per barrel [33] and Auckland of 13s [34], although it may reflect a discount for bulk purchases.

Although the promoters had hoped to issue 6,000 shares each of £1 value, they only achieved sales of 3,200, with not all purchasers meeting the required payments in full [35]. It would thus appear the company was under-capitalised from the start. Public records suggest it only built the three houses and one retaining wall noted above, and then declined. The company appeared in the newspapers on 2 February 1906, when the directors were charged with failing to make a statutory declaration regarding the affairs of the company [36], for which they were fined £1 and costs [37]. Less than two months later, on 20 March 1906, the Company ceased trading and was put into voluntary liquidation [38], although the process was not completed until 29 May 1934, 28 years later [39].

3. First Constructions

Nielsen and Atkinson, as the builders, were issued with building permits by the Melrose Borough Council on 10 March 1904 for a concrete block shed and on 27 April 1904 for a hollow concrete block house on the same site, although the permit plans and associated documents no longer appear to exist [40]. On 26 April 1904 a permit was issued by the WCC for a concrete block retaining wall [41] and on 10 October 1904 for a two storey house [42], while the Melrose Council issued a permit on 11 December 1905 for a small house made of hollow concrete blocks [43]. These four constructions exist in 2013.

3.1. Lyall Bay House

Neither the building permit nor the plans for the house mentioned in the newspaper advertisements as built at Lyall Bay, Wellington, by October 1904 [44] have been found in the WCC Archives.

Figure 2 shows a house located within the boundaries of the land belonging to the Company and built of hollow concrete block matching the Palmer patent. The block face is of a similar design to that in the other houses known to be built by the company, suggesting it is the first hollow concrete house built in New Zealand. At the front of the section, there is low retaining wall made of the same hollow concrete blocks, and similar retaining walls are found in front of four other nearby houses.

Figure 2: Lyall Bay, Wellington house

The external blocks are similar appearance to those shown in US patent 727,427.and NZ patent 19,038. They exhibit the shaped central core, which permits the making of half bricks, as described in the patents [45]. The measured size (with allowance for mortar) matches the dimensions given by the company in a letter of 15 Jun 1904: “*the size of a full block is 31 inches long 9 inches high and gives a wall 11 inches over the rock face*” (79 cm x 23 x 28 cm) [46].

Modern hollow concrete block construction must meet the seismic requirements of the New Zealand Building Code Clause B1 Structure, which require appropriate levels of reinforcing and for the hollow cores to be grouted (Verification Method NZS 4230:2004 or Acceptable Solution NZS 4229:2013 [47], effectively turning the blocks into a formwork. The current owner of the Lyall Bay house recalled seeing visible metal in the block cores when viewed from the attic, although as the house is very close to the beach wind-blown sand had entered the attic and filled the empty cavities.

A non-destructive inspection was undertaken by Detect Services Ltd using a Conquest Concrete Imaging device. The Conquest unit (manufactured by Sensors and Software, Canada) uses Ground Penetrating Radar (GPR) to create a pseudo image inside the concrete wall. A linear scan explores the area directly underneath the sensor, while a grid scan can be used to create a 2-D map. In both cases, views at user selected depths can be provided in pseudo colour. GPR detects materials with different density so can be used to detect steel or other metal within a concrete wall.

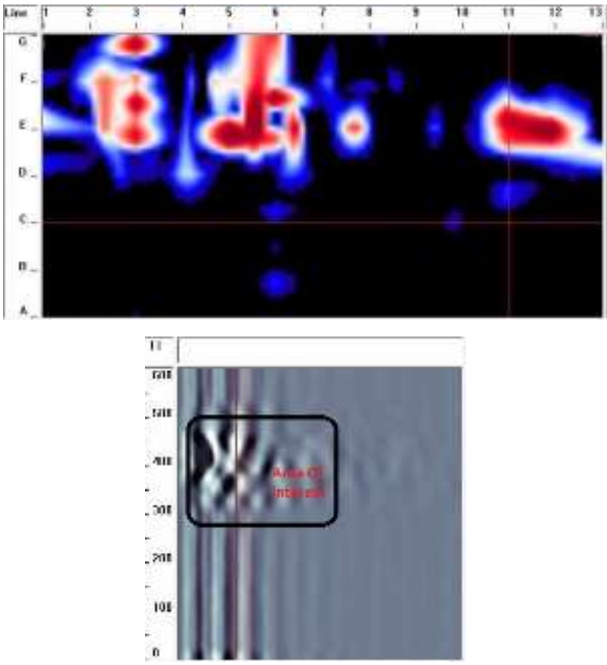

Figure 3: GPR View of Hollow Concrete Block Wall

The inspections of the external wall in two different rooms on the same side of house found in each a line of pieces of denser material at a depth of 15 cm, as shown by the red and blue areas in Figure 3.

The specifications for the Roseneath House (see below) include the requirement:

> *“All jointing to be done according to the directions of the Architects, also supply and fix all gun metal dowels and cramps as required and directed* [48].”

It would therefore seem likely that this denser material is gunmetal (a bronze alloy) providing vertical (dowel) and horizontal (cramp) strength to the wall.

3.2. Retaining Wall

On 26 April 1904, Nielsen and Atkinson applied to the WCC for permit to erect a retaining wall in Thompson Street using “*Palmers hollow building blocks, 10 inches No 4*” with the “*top with a 12½” x 6” moulded coping stone with pitched top and ovala* {sic} *edges*” valued at £30 [49]. The wall, which still exists (Figure 4), is on a sloping footpath and ranges from 6 to 10 blocks high with the footing beneath path level.

Figure 4: Retaining Wall, Thompson St, Wellington

3.3. Roseneath House

On 28 September 1904, Nielsen applied to erect a dwelling at Roseneath, Wellington, using “Palmers Patent Hollow Building Blocks” for all exterior and interior walls, as well as the chimneys [50]. The five bedroom, one bathroom house, valued at £1,000 (Figure 5), was built for W H Fordham, one of the original subscribers to the company, who in 1905 sold it to Alfred George East (the promoter of the company), who retained the ownership until 1909.

Although the design used rock faced block on the exterior corners, the remainder of the house and outbuildings were constructed of plain bock. The partially-rock faced corner blocks (Figure 6) are unusual as they are 1 + 1.5 block dimension. Palmer’s patent (Figure 1) shows a 1 + 0.5 block dimensions [51] as does Nielsen’s letter to the WCC which notes “*the corner block is made in one piece 32” one way and 16”* the other which alternately laid in the wall produces a sold corner and a perfect bond of 16” ” [52].

The house specifications call for mortar “*composed of six parts of clean fresh water sand, one part well* *burnt stone lime and two parts approved Portland Cement. No joint to exceed ¼ inch in thickness*" suggesting reasonably robust bonding. The plan shows 14 in blocks were to be used on the lower storey and 9 in on the top storey [53].

Figure 5: Roseneath House, Wellington 1904

The interior walls, timber-lined inside the house but left unfinished in the service building, were also of hollow block with supporting block foundations.

Figure 6: Rockface corners with fair faced hollow concrete block walls, Roseneath House 1904

The current owners are the tenth since the house was built. The story passed down from owner to owner is the blocks had been imported from America. In order to test this, 2 cm diameter plugs were taken from blocks in the basement of the house and standard petrographic thin sections were made by the Geology Department, Victoria University of Wellington. In both samples, the greywacke sand appeared to come from the same source. The location was most probably from the North Island of New Zealand and there was no indication it was imported sand [54]. Coupled with the evidence from building permit plans and specifications, this confirms that the house was built of locally made hollow concrete blocks

3.4. Holiday House

Nielsen's next, and last, hollow concrete block house permit was issued on 11 December 1905 for a two bedroom house, value £180, on Para Crescent (now Queens Drive), Lyall Bay, Wellington [55].

Although the plan drawing shows only plain face blocks, as built there are alternating two courses of rock face block with one of plain block (Figure 7). The house also has the same corner block dimensions as the Roseneath house. The specifications called for 12 inch red pine (rimu) skirting and skim coat plaster over the interior walls.

Figure 7: Rockface interleaved with fair faced hollow concrete block, Lyall Bay Holiday House 1905

Nielsen built a second cottage on the adjacent site in 1907, but as the NZ Hollow Concrete Block Co. Ltd was then in voluntary liquidation the house was built with a timber frame and rusticated weatherboard [56] – timber pretending to be stone, rather than concrete pretending to be stone.

4. After Wellington

Hollow concrete block making machinery was soon being used in other parts of the country. Contemporary reports show that hollow concrete block was being used widely by the end of the decade (first year of use in brackets): Timaru (1906); Whangarei (1906); Auckland (1907); Lower Hutt (1907), Dunedin (1908); Westport (1908);

Invercargill (1909); Cambridge (1909); Napier (1910); Hawera (1910); Christchurch (1910); and Wellington (1910).

5. Conclusion

Harmon S Palmer patented his hollow concrete block system in US in 1900. By 1904 a patent application was made in his name in New Zealand. However, it was not until 1905 that the patent process was completed, although for the Palmer's 1903 machinery rather than the block system.

In 1904 Niels Nielsen, one of the two New Zealand patentees, started to actively promote use of the blocks initially building part of a warehouse in central Wellington (since demolished). Nielsen promoted the fire, moisture and ventilation advantages of hollow concrete block construction, both to the public through newspaper advertisements and through letters to the local council. In this he followed the practices of early North American block producers.

Prospects must have initially looked good for the Wellington (later New Zealand) Hollow Concrete Block Company, although it failed to reach its capital raising expectations. The business provided product for at least three houses and one retaining wall, but was not financially successful and was put in liquidation in 1906. The houses and wall are still in use, although none currently (2014) has any historic designation.

The Wellington business was soon followed by businesses in other parts of the country but, as seems too often to be the case, on its demise its cutting edge role in establishing hollow concrete blocks as an acceptable construction material was quickly forgotten.

This research has shown that there is a direct link between the US patents of Harmon S Palmer and New Zealand's first hollow concrete block constructions. How the patent travelled to New Zealand is unclear, but it shows that even in the days of steam ships, the travel of technology was limited only by the speed of faster mode of transport, with New Zealand only a matter of months behind the latest events in the US

It has also shown that although the New Zealand Hollow Concrete Block Company Ltd did not prosper, it laid the foundations for the New Zealand hollow concrete block industry.

6. Acknowledgements

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LEARNING FROM FAILURES: USING HISTORICAL ENGINEERING PROJECTS TO TEACH BETTER PROFESSIONAL ENGINEERING SKILLS

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Abstract
The state of the art of engineering knowledge has historically often improved following reviews of major disasters and engineering failures. It is not desirable however for professional engineers to only improve their understanding and skills by “learning from their mistakes”. A new final-year engineering course for Civil and Natural Resources Engineering students at the University of Canterbury aims to get students to learn more from other people’s past mistakes. A major component of this course is a group project where students investigate notable engineering “failures” from the past century and try to determine the causes behind them. As well as any direct technical reasons for each failure, students are challenged to identify the more “non-technical” issues that contributed to the ultimate denouement, including human errors, ethical shortcomings, and regulatory omissions. Using this exercise, it is hoped that students will learn to recognise common “warning signs” in their future projects that may be pre-cursors to more catastrophic potential outcomes.

1. Introduction

Various commentators have noted that the state of the art of engineering knowledge often tends to make the biggest improvements following reviews of major disasters and engineering failures (e.g. [2], [4]). For example, design standards for buildings in earthquakes were first introduced into New Zealand in 1935 following the 1931 Napier earthquake [1]. Typically the process involves investigating what didn’t perform as expected during the event and then devising some new standards or methods to resolve these shortcomings. It is not desirable however for professional engineers to only improve their understanding and skills by “learning from their mistakes”.

Also, in many cases, there are a number of intermediate steps that contributed to the ultimate “failure event”, many of which are “non-technical”. These could include human errors (both individual and collectively via groups and organisations, [6]), ethical shortcomings (e.g. cover-ups, pressure from other parties), and regulatory omissions (e.g. inadequate checks, failing to meet required standards). In hindsight, the identification and elimination of some of these issues may have been sufficient to prevent the final undesirable result.

This paper summarises the development of a new final-year engineering course at the University of Canterbury (UC) that seeks to get students to learn more from other people’s past mistakes. A major component of this course is a group project where students investigate notable engineering “failures” from the past century and try to determine the causes behind them, both technical and non-technical.

2. New Professional Engineering Course

In 2013, as part of a review of the undergraduate curriculum, the Department of Civil and Natural Resources Engineering at UC introduced a new compulsory final (4^{th}) year course to their Bachelor of Engineering (BE(Hons)) programme. The course, ENCN470 (“Professional Engineering Development”), had a stated aim to *“further develop and refine students’ professional engineering skills, using Civil and Natural Resources Engineering projects and issues for context.”* The course included consideration of topics such as risk management, systems thinking, the engineer in society, and engineering ethics, as well as continuing to develop students’ skills in teamwork and communications.

IPENZ, in its five-yearly accreditation of UC’s engineering programme, had identified the need for these “non-technical” attributes of professional engineering to be better covered in the undergraduate curriculum. Although some of these topics had previously been presented elsewhere in the old curriculum, they tended to be subservient to the technical content of the courses; thus it was possible to pass without demonstrating mastery of them. This new course allowed these topics to be the core component of the final assessment.

An underlying theme for a large part of the ENCN470 course is the concept of “learning from experience”. Noting that the students are still relatively limited in their own experience of the engineering industry, the intention is to instead draw on lessons learned from *other* engineers’ experiences, via case studies, guest lecturers, and the students' own investigations. Some assignments in the course for example require the students to monitor and comment on engineering-related news in mainstream media and to attend and report on a number of industry events (e.g. IPENZ seminars, technical society presentations).

2.1. Teaching about Failure

A lot of engineering education tends to rely on providing students with "recipes" for success; for example, design techniques and calculation methods that have proven to be successful in the past. There is a danger however that such past success may blind professionals from the potential dangers of new projects where the previous circumstances cannot be completely replicated. These dangers may be due to extending the existing engineering knowledge beyond what has been tested, or it may be due to having different personnel, site, and organisational constraints.

The ENCN470 curriculum includes a series of topics designed to help students appreciate the value in learning about engineering failures and to give them the necessary investigative tools:

- Generic types of failure (e.g. objectives not met, undesirable side-effects); Effects of failures on different entities (people, property, level of service, etc).
- Reasons for investigating failures (punitive measures, avoid future failures); Issues with formal Inquiries.
- General causes of failures (due to aims, organisations, methods, people); Human errors (skills/rules/knowledge-based); Organisational and group behaviour (e.g. "groupthink").
- Systems representations of complex engineering concepts (entities, relationships); Characteristics of good systems descriptions (completeness, discrimination, naming, etc).
- Models for failure investigation ("Swiss Cheese" model, spray diagrams, multiple cause diagrams); Formal Systems Model concept.
- Risk management strategies for projects/ activities (avoid, reduce, mitigate, etc); Use of design standards and awareness of their limitations.
- Legislation affecting engineers; Liabilities under law; Environmental planning & legislation (RMA, Environment Court, town planning).
- Ethics vs morality and the law; Schools of ethical thought (teleology/deontology, utilitarianism); Tests for ethical decision-making; Professional engineering codes of ethics.

The ENCN470 course also notes that one problem in industry can be a loss over time of "institutional memory", as new generations of engineers come in. Petroski [5] identified an interesting sequence of new types of bridge failures approximately 30 years apart since the 1840s, and hypothesised that this time gap may represent the point at which the next generation forgets about the lessons learned from the (now retired) previous generation when testing the bounds of new designs.

Some other courses within this programme and at other universities with engineering degrees do present case studies of notable failures as part of their content. However, these courses tend to focus on the technical aspects of the failures (as a way of illustrating the technical theory being introduced) and overlook the more complex nature of human failings, and the constant tension of costs and benefits (i.e. risk vs reward) on many projects.

Many other undergraduate engineering programmes cover professional engineering topics (e.g. the University of Auckland's Faculty of Engineering has a compulsory final-year course called "Professional and Sustainability Issues"). However, to the best of our knowledge, the author is not aware of any other engineering programmes in Australasia that cover failure investigation in a broad-based manner as this new curriculum does. Elsewhere however, a growing number of engineering faculties are offering courses in "forensic engineering" (e.g. Columbia, New York; Cleveland State University), using case studies such as those studied here to teach students about multi-disciplinary failure analysis.

2.2. Engineering Failure Case Study Project

A major component of the ENCN470 course is a group project where students investigate a notable engineering "failure" from the past century and try to determine the causes behind it. As well as any direct technical reasons for each failure (e.g. structural failure of a beam), students are challenged to identify the more "non-technical" issues that contributed to the ultimate denouement, including aspects of human error and failings in ethical behaviour, risk management, and regulatory obligations. Using this exercise, it is hoped that students will learn to recognise common "warning signs" in their future projects that may be pre-cursors to more catastrophic potential outcomes.

The students work in groups of four or five, allocated to projects on the basis of their submitted "top five" preferences. It should be noted that, by this stage of their studies, students are able to choose elective courses in their sub-disciplines of interest (e.g. structural, geotechnical, fluids, environmental, transport). Therefore the aim is to allow them to investigate a project of particular technical interest to them. Table 4 provides a list of some (not all) of the projects that have been offered to students to date; as well as spanning both New Zealand and international contexts, and over a broad range of eras, they encompass a range of different technical fields. There were 26 case studies investigated in 2013, and 32 in 2014, with more than half being investigated in both years.

The project is also designed to test students' general engineering skills in a variety of ways. Each group is required to produce a final written report and deliver an oral presentation, both to a high standard. They are also required to initially prepare a detailed project plan, outlining the tasks, roles, timelines, quality controls, etc necessary to complete the project, and later to formally peer review a draft of another group's outputs.

Table 4: Examples of Projects investigated (not all)

Mapua Contaminated Site Clean-up, Nelson (1990's)
Levin Landfill project, Horowhenua (1950's-2000's)
Lake Manapouri Power Scheme (1960's-70's)
Project Aqua hydro scheme, North Otago (2003-04)
Opuha Dam Breach, South Canterbury (1997)
Whaeo Canal Failure, Bay of Plenty (1982)
Matahina Dam, Bay of Plenty (1967-87)
Malpasset Arch Dam, France (1959)
Abbotsford Slip, Dunedin (1979)
Eschede Hi-Speed Train Disaster, Germany (1998)
Sydney Cross City Tunnel Toll Road, NSW (2000's)
New Orleans levee failures (2005)
Central Artery/Tunnel Project, Boston (1991-2007)
Ballantyne's Fire, Christchurch (1947)
Napier Earthquake Fire (1931)
South Rangitikei Rail Bridge Collapse (1975)
West Gate Bridge, Melbourne (1970)
Quebec Bridge, Quebec City, Canada (1907/1916)
Kaimai Tunnel collapse, Bay of Plenty (1970)
Stadium Southland collapse, Invercargill (2010)
Cave Creek platform, West Coast (1995)
Hyatt Regency Walkway, Kansas City (1981)
World Trade Center, New York (2001)
Hartford Civic Center, Connecticut (1978)
I-35W Mississippi Bridge, Minneapolis (2007)
Charles de Gaulle Airport Terminal 2E, Paris (2004)
King Dome Failure, Seattle (1994)
Silver Bridge collapse, Point Pleasant, Ohio (1967)
Love Canal contamination, Niagara Falls (1953-78)
Southerner level crossing collision, Rolleston (1993)

2.2.1. Project Tasks and Questions

The following tasks and questions need to be resolved as part of each group's investigations:

- Concisely describe the entity/project in question and the circumstances leading to the failure(s).
- Prepare at least one **systems model** of the entity/project, making it clear whose perspective/ world-view is being presented (and why). Compare the systems model against an ideal Formal System Model, as described in [7] and discussed further below in Section 2.2.2.
- Prepare a **risk management matrix** of potential risks/hazards prior to the failure(s), indicating the relative likelihood and consequences of each risk/hazard. How did the actual risks/hazards contributing to the failure compare with other risks/hazards that didn't eventuate?
- Identify any potential **ethical issues** that may have arisen before, during or after the failure(s). How might events have been different if certain ethical decisions had been made differently? (e.g. if participants had followed IPENZ's Code of Ethics)
- Consider the **regulatory environment** that was present before or during the failure(s). How might events have been different if the entity/project was operating under present-day legislation/regulations in New Zealand?
- From the above analysis, determine what were the **underlying causes or contributory factors** behind the failure(s).
- If you were undertaking a formal Inquiry into this failure, what would you be **recommending** (both technical and non-technical) to try to prevent a similar type of failure from happening again? What lessons are there to learn for engineering entities/projects in general? How do these recommendations compare with what actually happened after the failure(s)?
- What were the likely effects/implications of this failure and its subsequent aftermath **on society in general**? For example, changes in our daily lives, or changes to perceptions of engineers and engineering projects.

Students are able to source whatever material they can find to help their understanding and to derive their conclusions, via online or Library resources. At the end, each group is expected to have a comprehensive overview of the factors that led to the failure being studied, and how a failure of this nature could have been prevented.

2.2.2. Formal Systems Model

Fortune and Peters [3] outlined a technique for investigating failures in projects that compared the actual events and entities involved against an "ideal" state of affairs. A visual model is created to represent the project itself (the "system"), surrounded by the other aspects of the organisation(s) undertaking the project (the "wider system"), which in turn is surrounded by other physical and social factors external to the organisation (the "environment"). This so-called "ideal" Formal Systems Model (FSM, shown in Figure 1) aimed to represent all of the necessary components for successfully completing a project, e.g. having a suitable sub-system monitoring the project's performance.

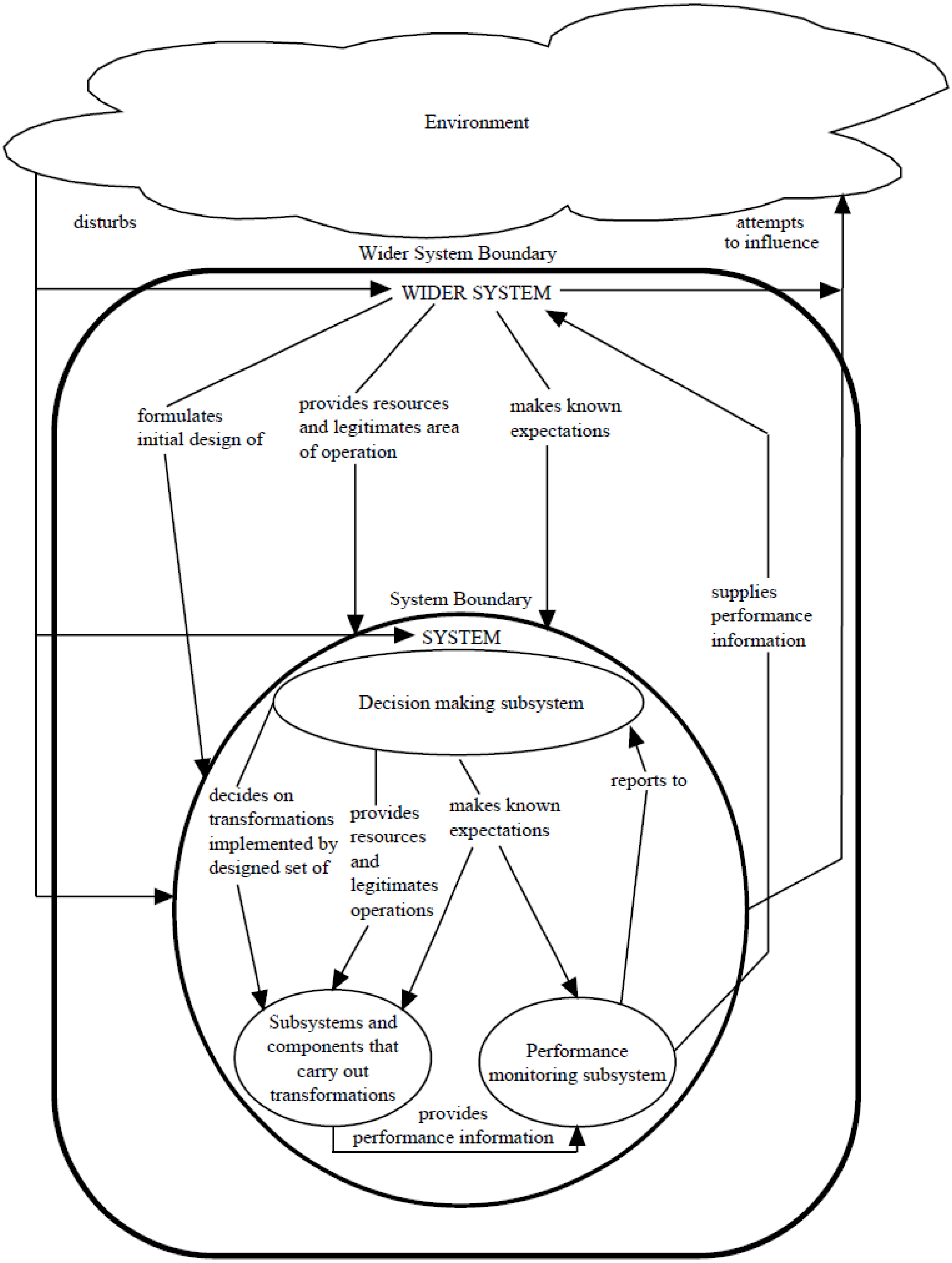

Figure 1: General Structure of an “ideal” Formal Systems Model for a successful project/entity (from [3])

A key part of the assignment requires students to construct a systems representation of their project in the FSM format. For their identified failure(s), they could then determine what deficiencies were present in their systems model relative to the ideal FSM. For example, they might have noted that the governing organisation (the "wider system") did not make available sufficient resources to complete some aspect of the project.

The FSM approach provides a useful systematic method for identifying the likely non-technical reasons for the project failure. It offers a consistent framework with which to test the quite varying circumstances affecting the many different projects being studied (32 in 2014).

3. Issues Identified with the Group Project

An interesting challenge for some groups is to first identify what exactly the "failure" was in their project. While some projects (e.g. Opuha Dam breach) have a fairly obvious physical failure, others involve a series of ongoing events that could be considered failures (e.g. Boston "Big Dig", featuring accidents, cost over-runs, etc). Still others seem even less obvious whether any notable failure had occurred at all; e.g. the Chesapeake Bay Bridge-Tunnel (Virginia) stumped one group because the facility is still operating today (despite a few major ship collisions). A useful idea suggested to some groups is to identify what would have been the likely project objectives at the start of the venture and then consider whether those objectives had been successfully met. For example, some of the aims of the Chesapeake Bay Bridge-Tunnel were to open up development of the Delmarva Peninsula, and to operate an economically sustainable toll operation, neither of which has been fully achieved.

Some groups encounter difficulties discovering the regulatory and engineering environments of their projects, due to their considerable distance in time and space from present-day New Zealand. Where these information gaps cannot be resolved, the students are asked to focus on how the project would have fared in present-day New Zealand, taking into account current legislation, IPENZ requirements, and so on.

Although students are encouraged to concentrate on the non-technical aspects of their projects, many still focus too much on the technical reasons for the failures. Given the predominant emphasis in their studies on technical subjects, such as load capacities and material properties (and their likely greater comfort with these topics), this is perhaps not surprising. In many cases, students may have also been influenced by an official "Commission of Inquiry" report obtained for their project, most of which have historically been limited in scope to technical aspects of the failure.

Some of the projects investigated have considerable similarities between them, both in terms of the facilities involved and the failure mechanisms. It is pertinent to note that clearly the lessons of past failures have not always been heeded. For example, one group presenting on the Hartford Civic Center collapse (due to snow in 1978) concluded that the findings from this investigation should *"prevent a reoccurrence in the future".* However another group had just presented on the Stadium Southland collapse in 2010, a similar publicly-owned sports facility also damaged by snow loads!

In fact, a common theme identified was the role that many public agencies like Councils played as both owner/developer and regulator for many of the projects studied. Clearly there were often difficulties prescribing the same level of independent scrutiny to their own projects as is done for private ventures. This point has subsequently been picked up for highlighting in more detail in the ENCN470 curriculum.

It is interesting to note that most of the projects studied were subsequently repaired or a revised version completed, rather than being abandoned. This suggests that there was merit in the original objectives of the facility, rather than it being "doomed from the start". Many of the projects were however the catalyst for improvements to regulatory requirements or engineering best practice. For example, the similar failures of the Ruahihi Canal (1981) and the Wheao Canal (1982) were instrumental in the formation of the New Zealand Society of Large Dams (NZSOLD).

Some other aspects of the ENCN470 course experienced "teething troubles" in its first year (2013), partly due to a reluctance by students to spend time on "non-technical" topics deemed less important to their careers. However, feedback on the failure case study project was generally positive from the students. A couple of quotes from the student course evaluation illustrate this:

"The group project was good; it was quite fun to learn about a failure while my peers were learning about something completely different and then we could come together to share it with each other in the presentations."

"The failure project was a good learning tool. Before starting the project, many concepts were just vague things that one ought to do. The project was a framework to see them in action."

The project also provides a practical way to introduce aspects of engineering heritage to the students without it coming across as a "dry" history lecture. Many of the projects studied are considered touchstones of modern engineering practice (i.e. when existing practices were questioned or new practices introduced), and it is useful for students to appreciate the context of why it is that modern professional engineers “do the things they do” in current engineering.

4. Conclusion

The new ENCN470 course has enabled a number of “non-technical” professional engineering skills to be assessed in a more direct (yet still contextually relevant) manner. By focusing on how engineering projects can fail in a variety of ways, students gain a set of skills to help them identify how things can go wrong, for both technical and non-technical reasons. Using the historical case study project, it is hoped that students will learn to recognise common “warning signs” in their own future projects that may be pre-cursors to more catastrophic potential outcomes. At a time when major events like the Canterbury Earthquakes have raised public awareness of engineering practices, this seems like an important skill for our future students to have.

5. Acknowledgements

The author would like to gratefully acknowledge the support of Dr Lloyd Carpenter (now at Lincoln University) in assisting with the first (2013) instance of this course. He also thanks other colleagues in the Civil and Natural Resources Engineering Department for their contributions to the development and running of this course.

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SAWMILL ENGINEERING IN NEW ZEALAND

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Abstract

This paper investigates the development of sawmill engineering in New Zealand's native sawmills from 1838 until their virtual end in the 1980s, which involved around 2000 mills. A broad description is provided of the design aspects of those sawmills. The role of engineers and others in technology improvement is investigated. A steer is provided for further detailed study of this topic.

1. Introduction

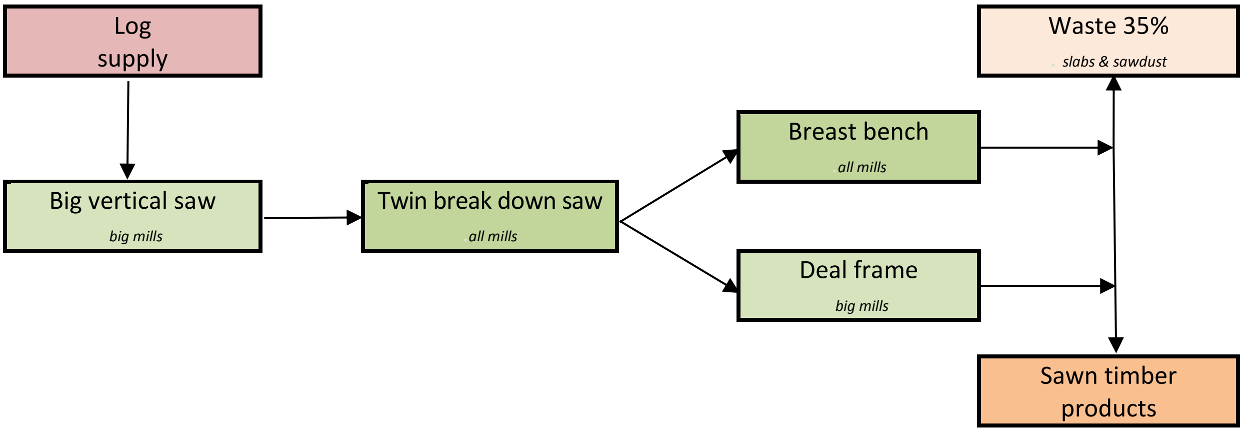

Figure 1: Schematic diagram showing process sequence of the principal saws typical of all native mills built after 1900 (breaking down saw plus breast bench saw) and the additional saws typically found in a large mill (add in a big vertical saw plus a deal frame). In some mills from the 1950s band saws replaced the big vertical and twin break down saws.

Addressing the theme of engineering and nature, this paper considers the engineering heritage of the production in New Zealand of timber, one of nature's most valuable, utilised, and renewable materials. The scope is sawmill engineering in the native timber industry, noting that plantation pine sawmills are an equally big story that is not touched on here. Much of the historic information is drawn from Mahoney's *Sawmill Technology in New Zealand: Our Native Mills* [1]. Colin Zeff, having had a professional career in the sawmilling industry, provides valuable design insights. An estimate of technology scale is that nearly 2000 native mills were built 1838–1980. This paper's objectives are:

1. To provide a broad description of the design aspects of sawmills
2. To investigate the role of engineers and others in sawmill technology improvement
3. To provide a steer for further more detailed study of this topic.

2. Chronology

An indicative outline of the era and technology:

1794	First round timber exports, Royal Navy spars, probably Kahikatea
1818	First pit sawn timber exports to Australia
1838	First sawmill: Mercury Bay, Coromandel; water powered; erected by a millwright
1841	First steam mill: Catchpool near Wellington; likely one saw
1842	First large mill: Cornwallis near Auckland; likely a frame saw plus circular bench
1880s	Twin circular breakdown saws introduced
1887	First band saw: P. Bartholomew, Levin
1902	First Radiata pine milled commercially at Temuka
1959	Exotic timber output first exceeds native
1980	Last native mill built: J. B. Cowan, Haast
1993	Last classic native sawmill closes: D. Cadigan, Three Mile, near Hokitika
2014	Lindsay & Dixon Tuatapere mill: last major indigenous mill continues in production

3. Native Sawmilling Overview

Sawmilling was amongst New Zealand's first mechanised industrial enterprises. This section briefly outlines the key elements of a typical native mill and its supporting infrastructure. This report will focus on engineering and operational aspects of the three principal sawing machines used.

The technical design of mills was done by four main groups of people: those with know-how gained from practical experience, engineering tradesmen, millwrights and professional engineers. Equipment manufacturers, both locally and overseas, did the design of most sawing machines.

Figure 2: Typical early small sawmill ~1882. The outdoor structure on the left is the vertical frame saw used to break down logs. Under cover, the steam engine is located centrally and a breast bench to the left.

Early mills as above were built close to the log source because of the difficulty of moving large logs. Sawing machinery was mounted on large logs set in the ground. Mills were dismantled and moved to a new site after five to ten years as the log supply distance increased or was exhausted. The capacity of mills progressively grew as supply increased because of low cost transport systems, like log floating and bush trams. The typical economic life of these mills extended to 20–25 years. From this progression there emerged a skilled group of sawmill engineers who learned about materials handling, logistics, log geometry and timber yield, and most important of all, sawing technology.

From the information and images available New Zealand's early sawmills from the 1840s to 1880s were a varied lot! In addition to adapting imported machinery to conditions here, our early millers had to learn the capabilities and limitations of a totally new range of wood species. For example, some woods like Puriri and Maire are very hard to saw, Rewarewa and Pukatea collapse while seasoning, and Tawa and Kahikatea are prone to decay in use.

Many early sawmills seem to be poorly laid out, labour intensive, and with small output capacity. The key saw for log break down work was the frame saw with its vertical blade. It was basically a mechanised pit saw. Frame saws were the ones that started the industrial revolution for wood back in the 1600s but they were painfully slow. Over time much thought went into improving the productivity of mills.By 1900 New Zealand native sawmills had evolved into a typical design (see Figure 3), with two key sawing machines: twin circular break down saws and a breast bench circular saw, all powered by steam. Such mills are described in Malfroy [2] and Stewart [3]. Larger mills varied this basic scheme. They had additional machines to boost production: typically a vertical breaking down saw, second breast bench, deal frame and docking saw. The band saw for breaking down was adopted later.

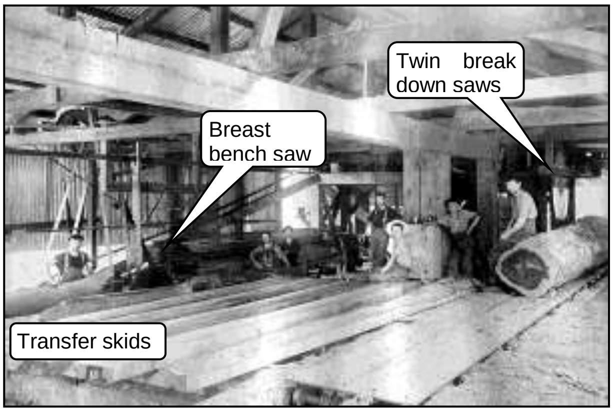

Figure 3: Typical native sawmill layout ~1910. Key technology elements are: the twin break down saws, flitch transfer skids and breast bench.

A typical mill building, as in Figure 3, was say 23 metres (m) long and 5 m wide, built of timber with an iron clad roof. Columns supporting wooden roof trusses were tree trunk sections set in the ground. Saw machinery foundations were whole logs set into trenches in the ground. Mass concrete was used as a foundation for the steam engines driving the larger mills. Some mills built from the late 1940s had concrete machinery foundations.

Material handling systems at mills were important but typically were primitive and labour intensive. Key elements were: log skids sufficient to hold several days cutting, timber transfers between saws, sawdust disposal, wood waste and sawn timber yards to hold up to six months production which was sufficient time for air-drying. Drying sheds and dry kilns were uncommon. The fork lift and straddle carrier were adopted late at such yards. There was no native timber by-products industry. Sawdust and off cuts, typically 35% of the log volume, was largely discarded as waste, creating problems.

The range of power sources used in mills was the same as those used in many other industries of the era. They evolved through water, steam, and internal combustion to electricity. No specialised power engineering was required. A notable feature was the complex mechanical power distribution systems adopted because mills were powered from a single source. Many mills were underpowered so not all the saws could work at once. The most distinctive power technology item was the Dutch Oven, which very efficiently burned sawdust waste to raise steam in mill boilers.

Wood processing at mills was not common and at best typically just planers and moulders. The development of the industry relied firstly on coastal shipping and railways to transport the rough sawn timber to the fast-growing towns and cities and to the export ports. Rough-sawn timber was re-sawn, dried or 'seasoned', and planed and moulded as required in processing plants set up in the centres of population. Preservation was largely limited to tawa timber. The only engineered timber product was the output of three plywood plants.

Five trade skills were found at sawmills and four of these were distinctive to mills: millwright, saw doctor, timber classer and benchman. The fifth, engine driver certification, was cross-industry. Working conditions were very basic with hours ruled by the mill whistle. A five and a half day week was common, and much of the work was arduous, noisy, done in low light and hazardous to eyes, fingers, even limbs. Accidents and fatalities were far too frequent and for too long inquests ruled grisly mill deaths as unavoidable.

Living conditions at sawmill settlements also merit study. Many mills were set in remote locations at the end of rudimentary access roads. Services like electricity and phone were rare. Mill houses were so primitive that the government got involved in a Sawmill Worker's Housing Scheme 1946–50. Single men were accommodated very basically with a cookhouse and huts. Schooling was also an issue if married men were to be retained.

Sawmilling became progressively bound by legislative requirements that impacted on design. In approximate order of introduction these include: coroner's investigations 1858, company registration 1860, boiler inspections 1874, boiler attendants 1894, machinery inspections, sawdust in waterways 1908, rural fires (affecting waste wood disposal) 1921, sawmill registration 1944, and timber stacking 1948. Major sawmilling organisations of the era were the Timber Workers Union, Sawmillers Federation, and Forest Service, founded in 1900, 1917 and 1919 respectively.

4. Twin Break Down Saws

Twin break down (breaking down) circular saws were the first stage of sawing in a typical indigenous mill, like the example in Figure 4 at Oio, in the central North Island. They cut heavy logs into flitches for the breast bench. Figure 4 shows twin circular saws and a heavy flat wooden bench drawn along a bed of rollers. Visible right of centre, twin saws of around 1800 millimetre (mm) diameter are mounted one above the other. Their size and momentum, whizzing around at 300 revolutions per minute (rpm), made them frightening to be near. They are stopped for the photo. Visible to the right is the pulley and belt drive to the upper saw. The heavy wooden bench has a slot along most of its length to allow passage of the lower saw.

Figure 4: Typical twin circular break down saws, 1930s. The log is positioned laboriously on a flat top bench. The belt and pulley drive system is evident.

The circular saw blade is not just a disc of steel plate with teeth cut into it. It is necessary for a saw doctor to hammer the plate to tension the saw so when it is running at speed the saw is stiff and cuts a true straight line. The saw doctor was also needed to shape and swage the teeth to provide a sharp cutting edge and clearance for the saw in the cut. After the mill manager, the saw doctor was the most important man on site, with the possible exception of the cookhouse cook.

The earliest known New Zealand example of this type of saw was in 1871 at Guthrie and Larnach's mill at Owaka, in the Catlins, Southland. Twin circular saws were latest technology. They superseded vertical reciprocating frame saws, boosting productivity tenfold. Twin 1800 mm diameter saws enabled logs of around 1600 mm diameter to be readily broken down. This technology was largely unchanged when native mills ended a century later. A challenger to the twin saw was the band saw. However, it had limited acceptance until the 1950s despite being introduced in New Zealand in 1887.

The main engineering improvement to boost twin saw productivity was the log carriage which replaced the flat bench. Unlike the labour intensive flat benches they replaced, log carriages were a greatly improved method of holding, turning, and aligning logs during the break down process. The key improvements were spiked arms that gripped the logs, uprights (called the set works) that the log was held against, and kickers that turned the log. With the log securely gripped, the speed of cutting could be increased which required more power delivered to the saws and to the log carriage drive system. The speed of returning the carriage after each cut was also greatly increased. Log carriage technology significantly reduced labour demands and greatly increased production. Despite this, relatively few mills had log carriages. A popular design was the Pacific Carriage, the name indicating its United States of America (USA) origins from the 1890s.

The twin break down saw went out with the indigenous sawmill and has no role in the sawmilling industry of today. In 2014, remaining New Zealand examples exist in three sawmill museums.

5. Breast Bench Saws

The breast bench was the second stage of sawing in a typical indigenous sawmill. Its role was to cut the heavy flitches into final sizes for retail sale. The benchman was a key and skilled job in mills, shown in Figure 5. He is pushing a heavy 250 mm thick flitch into the 1050 mm diameter circular saw blade, whizzing around at 450 rpm. The flitch will be passed repeatedly through the saw until it is completely cut into saleable boards. Working at the other end of the breast bench is the tailer out. At the completion of each cut, he sends the final sawn sizes to the load-out trolley and directs the flitch back to the benchman. Productivity was increased by employing a third man, often called the pin boy, to set the gauge (also called the fence) determining the width sawn on each pass. The mill manager will have advised the benchman what sizes were needed to meet customer demand.

Figure 5: Typical breast bench saw. These saws were labour intensive. The introduction of powered feed rollers reduced effort and increased productivity.

Breast bench technology is likely as old as circular saws and may date to the 1830s. New Zealand's earliest mills probably included a breast bench. When new it was latest technology boosting productivity up to tenfold compared to the early frame saws it replaced. It was an arduous job for early benchman to spend all day pushing heavy flitches into a circular saw. Improvement was required to raise productivity. Research suggests that by the 1890s manual feed rollers were commonly fitted to breast benches. Initially these rollers were powered by a third person called a leverman, who wound a crank. By 1910 engineering had improved and the rollers were powered, making leverman obsolete. In time powered return rollers were fitted to ease the work of the tailer out too. In this final engineered form the breast bench was a modestly sophisticated machine. It still had very low productivity compared to the saws of today. The main challenger to the breast bench's role was the deal frame, a highly engineered high speed multi-blade frame saw.

The breast bench was a dangerous machine that maimed and claimed lives. Machinery regulations eventually demanded that a safety guard, called the fin, be added. This followed tragedies where the whirring saw blade picked up flitches, hurling them back and killing benchmen. The curved fin is seen on the left in Figure 5. The benchman's badge of trade was the loss of at least a few fingers. The number of breast bench injuries and deaths is not recorded but Henry Hoyle's tale is tragic. Hoyle owned a Thames sawmill. In 1916 Holye lost his right arm clearing a chip from the saw blade and 17 years later he was killed in an accident using the same breast bench.

6. Band Saws

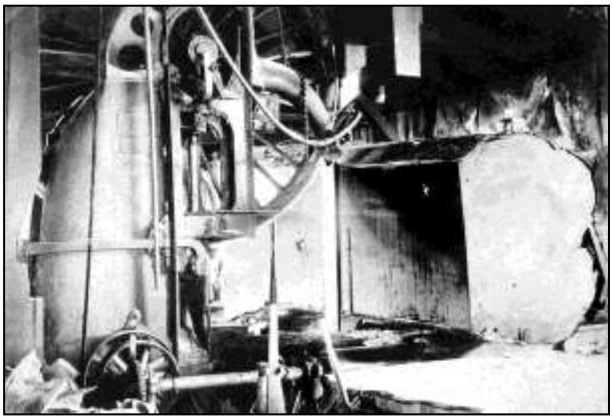

Figure 6: Typical band saw. This early example was used to break down large kauri logs in Northland. A carriage was required to hold logs firmly during cutting.

Band saw technology for large diameter logs was successfully introduced in the USA by Allis Chalmers in 1885. Two key advantages they offered were higher speed and lower sawdust waste. They soon spread globally and 1887 saw the first successful New Zealand use. While band saws had also been developed in Europe, New Zealand looked to the USA's West Coast for machines that could cut the relatively large log species harvested here.
Band saws were a great leap forward technologically. However, there were impediments to their introduction. [5, 6] Firstly, they were much more expensive to buy and install than locally made breaking down saws and breast benches. Secondly, they not only needed a whole new range of saw-keeping machines, but also a whole new

skill set to operate them. Thus in the early days of the band saw's introduction in New Zealand their speed and conversion advantages were often not fully realised. Only larger mills with access to high value resource could afford the capital investment required, the powerful engine to drive it, and training staff in the new way of handling logs and cutting flitches. Therefore, many mills that cut large girth logs retained the vertical break down saw. This old technology was developed in New Zealand to an exceptional size, a topic that demands further study.

Band saw blades lasted only half a shift before having to be removed for re-sharpening, swaging and benching. They were cumbersome and dangerous to handle. [7] Colin Zeff vividly recalls two band saw incidents in the late 1960s. At Stuart and Chapman's mill at Ross, West Coast of the South Island, the bandsaw blade came off at full speed because the saw guides failed, punched through the mill wall and bounced out into the yard, causing a general scatter. A few years later Colin was nearly killed. A bandsaw blade was folded awaiting sharpening in the saw shop at Henderson and Pollard's mill, Auckland. It broke loose from its restraints, breaking through the door to the next room, and cut Colin's wrist in the process. Just a few centimetres more and …

The flat-top carriage was not adequate for a band saw and a whole new family of powered log carriages were developed that could turn logs and flitches and set the dimension to be cut. The operator of the log carriage would ride on the carriage, controlling the cut pattern and the feed speed as the saw passed through the log, and manually turning down the cut slabs and flitches to pass on to the re-saws.[8]

Early bandsaws were not rated a success here because, allegedly, they did not cut our timber straight. This prejudice delayed their earnest adoption until the 1950s when the Forest Service insisted on their installation. From professional experience gained at the end of this era, Colin Zeff considers many of the supposed shortcomings of band saws simply related to a lack of skills and knowledge, meaning they were not being adjusted appropriately or operated and maintained for optimum results.

7. Big Vertical Saws

Figure 7: Big vertical saws were an anachronism that New Zealand developed into very large machines, possibly the last and largest of their type in the world. This example is unusual having two saw blades.

One consequence of New Zealand reluctance to adopt band saws was the continuation of the use of vertical saws, or frame saws, as late as the 1980s. These saws had a saw blade held vertically under tension in a reciprocating frame. As the frame moved up and down the log was fed through it. This type of saw had started the industrial revolution for wood in the 1600s. However, there were limitations to how fast the reciprocating fame could move without inducing destructive vibrations. Globally, vertical saws were superseded from the 1820s by circular saws and then band saws.

With exceptionally large kauri logs to break down, New Zealand chose to develop frame saws into what we called 'big vertical saws' (see Figure 7). Balancing was improved, along with beefed-up foundations and bracing. They were confined to the central and upper North Island. It is not clear if any other country in the world followed this technology path. Therefore, it is possible that the vertical saw was developed into its final and finest form in New Zealand 300 years after it kicked-off the industrial revolution. While the other saw types used here could be found around the world, the big vertical saws could be distinctively Kiwi, and this warrants further investigation.

8. Sawmill Design and Construction

The technical design of sawmills shared four pathways; know-how, engineering tradesmen, millwrights and professional engineers. Research to date has uncovered little investigation of this topic. Case studies may be the best method to develop an insight into how sawmill design engineering happened.

Know-how and practical experience obtained on the job, seems to have been a significant contributor to routine sawmill engineering. There seem to be many examples of mills being erected without the help of an engineering tradesmen or millwright.

Engineering tradesmen served a four year apprenticeship in an engineering workshop and studied at night school to pass theory examinations. They gained broad mechanical training and experience applicable to sawmill engineering. Many engineering workshops specialised in sawmill machinery which meant they, potentially, had the most proficient engineering tradesmen.

Millwrights specialised in design and erection of new mills and upgrading existing ones. They were also frequently involved in dismantling mills and re-erecting them on new sites. There was no millwright trade qualification, so more research is needed to understand the process of becoming a millwright, and also the relative roles of engineering tradesmen and on-the-job know-how.

Professional engineers seem to appear relatively late on the sawmill scene. Their role is obscured by their reluctance to publish professional papers. In 1873 English mechanical engineer, J Richards, complained that, worldwide, only two professional papers had been produced on sawmill technology to date [4]. This trend continued. Likely the first New Zealand professional sawmill engineer was Alex Entrican. He started with the Forest Service in 1921 as forest products engineer. His professional focus was to develop exotic timber processing and products, which is outside this paper's scope.

Initially sawmill equipment was imported. The Otago gold rush, starting in 1861, brought a huge demand for machinery. It was not long before there were a number of sizeable engineering shops able to build substantial machinery, including stationary steam engines. As shown in Table 1, these shops became involved in sawmill repairs and maintenance and worked out which equipment they could cost-effectively manufacture. Some machines were direct copies made without a licence agreement.

Equipment manufacturers were the main designers of sawmill technology. Machines were generally offered in standardised sizes but could also be customised. Manufacturers had the opportunity to continuously improve their technology in response to operational issues that arose.

Table 1: Sawmill Equipment Manufacturers.

Sawmill equipment item	Local production	Overseas production
Saw blades, *special steel*	-	☑
Band saw rig	some	☑
Pacific carriage	-	☑
Portable steam engine	-	☑
Stationery steam engine	some	☑
Internal combustion engine	-	☑
Deal frame	☑	☑
Big vertical breakdown saw	☑	-
Twin circular saws	☑	-
Table top carriage	☑	-
Breast bench - circular	☑	-
Underfired multitubular boiler	☑	-

In 2014, three museums preserve complete sawmill plants:

- Kauri Museum, Matakohe, Northland
- Timber Museum, Putaruru, Waikato
- Shantytown, near Greymouth, West Coast

In addition, two other significant complete sawmills (private property) survive at Waimiha, King Country and Marshlands, Marlborough.

9. Conclusion

Only a few highly selected engineering highlights can be included in the permissible size of this paper. The technology of the twin breaking down saws, the breast bench, the band saw and the big vertical saw were summarised. The role of engineers and others in technology improvement were outlined as well as possible given the readily available information. The overview section was structured to set a shape for a more comprehensive study that this major industry and its technology deserve. It is recommended that further study is done while the surviving specialists with the key knowledge can still participate.

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AN INGLIS PORTABLE BRIDGE SURVIVOR

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Abstract
This paper considers a significant early design of portable bridge, the Inglis Bridge. Portable bridges play a vital role reinstating crossings over waterways when bridges are destroyed by events such as flood, earthquake or warfare. The Inglis Bridge deserves special consideration in 2014, as it was developed by Charles Inglis for the British Army in World War 1 which started a century ago. The Inglis Bridge played a key role in 1918, supporting the advance of Allied forces that led to the end of World War One. An Inglis Bridge recently discovered in New Zealand is one of the last of its type in the world which remains in use. This paper looks at the war history of the bridge, the designer, the design concept, and the surviving examples. The New Zealand survivor deserves heritage recognition as an example of significant WW1 military engineering.

1. Introduction

Addressing the current World War 1 (WW1) commemoration theme, this paper considers an aspect of WWI bridging, the Inglis Bridges. It has been produced at short notice, following the rediscovery and identification of an Inglis Bridge in New Zealand a few weeks before the deadline for papers.

The common image of WW1 is of trench warfare, and tunnelling through muddy fields. However, portable bridging played a significant role in the ability of the Allied Forces to advance rapidly into territory vacated and systematically destroyed by the retreating Axis Forces.

The Inglis Bridge is a Warren truss bridge constructed of standardised steel components. The components are assembled into modules 3.66 metre (12 feet) long. Inglis Bridges could be built to any length by joining multiple modules. However, the allowable load decreased for longer spans. The Inglis design is significant as the world's first portable mass-produced bridge. Inglis bridges were used in France, Italy, and Palestine during WW1. An example has also been identified in Germany, on the Dutch border.

2. Charles Edward Inglis (1875-–1952) - Chronology

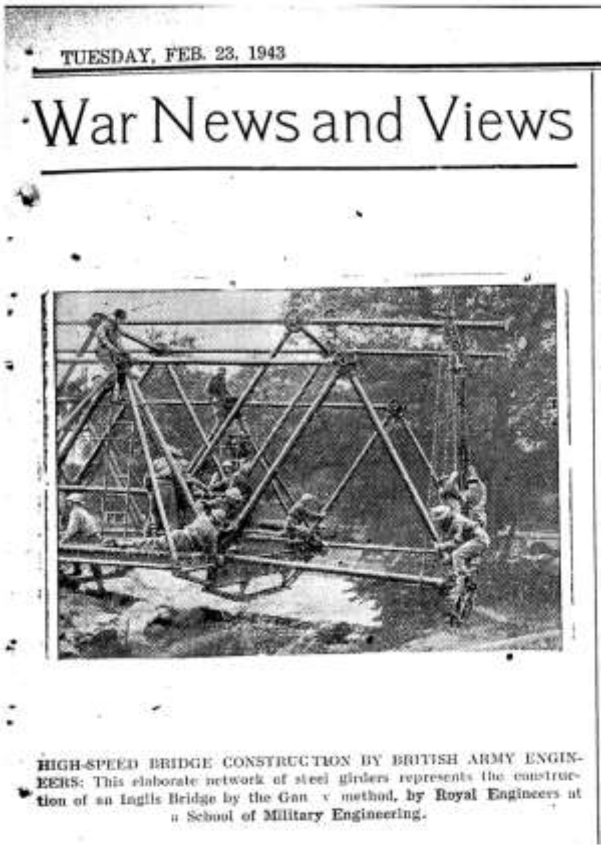
The Inglis Bridge, invented by Charles Inglis, predated the Bailey Bridge as a portable military bridge design. Inglis developed the portable bridge for the Royal Engineers, while he was an instructor at the Royal School of Military Engineering.

1875	Birth in UK
1895	Scholarship to Kings College, Cambridge
1899	Designing steel railway bridges as apprentice civil engineer
1901	Accepted as associate member of ICE
1901	Commences academic career at Kings College, specialising in the study of vibrations
1913	First version of Inglis Bridge developed for Cambridge University Officer Training Corps
1913	Published the first serious modern work on the fracturing of materials
1916	In charge of bridge design & supply, War Office
1919	OBE for war service
1919	Appointed head of the Cambridge University Engineering Department. Under Inglis' supervision the department became one of the best engineering schools in the world.
1923	Elected an ICE member
1924	Awarded ICE Telford Medal
1928	Elected ICE council member
1942	President of ICE
1943	Retired as Department Head, Cambridge
1945	Knighted
1952	Death: obituaries described him as the greatest teacher of engineering of his time.

3. Development of the Inglis Bridge

The Inglis Bridge was specifically developed for the British Army during WW1. The bridge was design to enable troops, artillery and tanks to continue to advance, and to be sustained with supplies.

Components were manufactured from 1916 onwards and taken to the Western Front. This type of bridge played a strategically important role in 1918, enabling the Allies' sustained momentum of the advance which ended the war. Speed was vital in preventing the Germans from regrouping and forming a new front line.



TUESDAY, FEB. 23, 1943

War News and Views

HIGH-SPEED BRIDGE CONSTRUCTION BY BRITISH ARMY ENGINEERS: This elaborate network of steel girders represents the construction of an Inglis Bridge by the Gan v method, by Royal Engineers at a School of Military Engineering.

Figure 1: Bay of Plenty Beacon, Volume 6, Issue 50, 23 February 1943, Page 3

In retreat, the Germans blew up existing bridges to stop the Allied advance. The stock of Inglis Bridges had been specifically designed to meet this challenge. Bridges could be customised for any situation, and quickly assembled from components by a team of engineers using a cantilevered gantry, made of the same components, and supported on rails.

4. Inglis Pyramid Infantry Bridge

Inglis first designed his 'Light Type' portable bridge in 1913 as a triangular section with Warren trusses as the two sides, and girder transoms supporting a narrow walkway for infantry. All the truss members were made of tubular sections for lightness of transport. The central top chord and the lower chords were shorter than the diagonal members.

Two of these triangular sections could be placed up to 4.8 metres apart, with a wider deck, for vehicles up to three tons, supported between them. This was called the 'Inglis Light Type Double Span'.

The Inglis Heavy Type Bridge was designed in 1915, in response to a request from the British Expeditionary Force for use in France. However, its triangular profile restricted the height of vehicles able to pass between the inclined trusses.

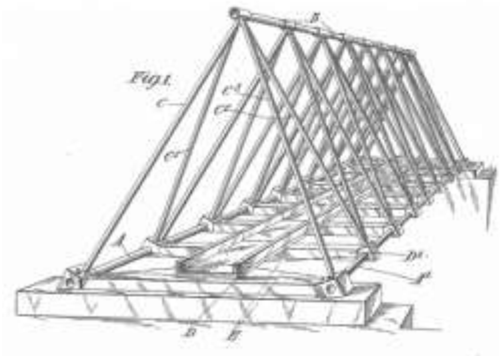


Figure 2: Patent drawing of Inglis Pyramid Bridge.

5. The Inglis Bridge Mark I, II, & III

As military vehicles became larger and heavier, military bridges had to evolve to cater for the growing live loads. Inglis maintained the use of steel tube members for the diagonals and top and bottom chords of his truss, but added steel girders between the top chords to make the trafficked area a more practical rectangular shape. The junctions were cast iron sockets which the tube pin ends were slotted into, with a flat face for connecting the transverse girders.

The bays were standardised to a 3.66 m (12 foot) length, and up to eight bays could be used in a single span. These were widely used in Europe in 1918, replacing road bridges destroyed by the retreating German Army.

Another significant use in 1918 was the Allenby Bridge across the Jordan River, connecting Jordan with the West Bank (now in Israel). It was replaced in the 1930s, with a larger steel truss structure. The current concrete bridge forms an important border crossing between Jordan and Israel.

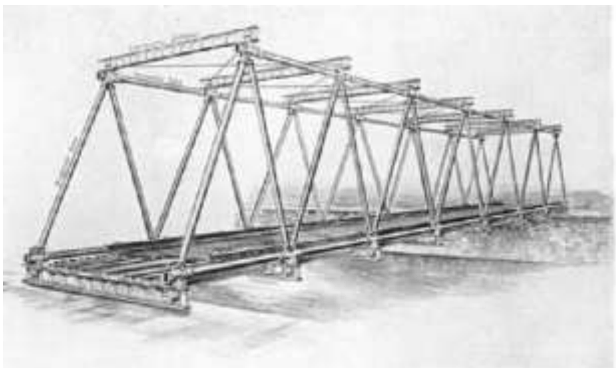


Figure 3: drawing of Inglis Mk II Bridge

The Mark II used stouter tubes, but a very similar design. Inglis made all the tubes 4.57 m (15 feet) long, to avoid confusion between different lengths of tubes.

Here is a field description from the record of the Canadian Engineers Corps: *Fortunately a new bridge, called the "Inglis Portable Military Bridge, Rectangular Type," had been invented by Captain*

Inglis, R.E., and was adopted by the British Army. This bridge was the Warren girder type and was composed of a number of identical bays, each twelve feet long, twelve feet high, and twelve feet wide. It was designed to carry a dead load of eighty-four tons distributed over a clear span of eighty-four feet.

Each part could be easily manhandled and the span could vary in multiples of twelve feet, ... *to suit the gap. The bridge was built on blocks in skeleton form with a counterbalance arm and jacked up on to a two-wheeled trolley. It was then pushed over the gap, the counterbalance removed, then jacked down on the abutment, and the decking laid.*

On the 28th of September, 1918, a bridge of this type was erected complete over the Canal du Nord at Marquion in twelve and a half hours actual working time under severe shell-fire. A party of approximately two hundred sappers was employed on the construction of the bridge with the necessary approaches and abutments. The span was one hundred and eight feet clear and the safe distributed load fifty-one tons.

The Mk II continued in the 1920s to be used in training, and developed into assault and floating bridges.

Figure 4: Building the Inglis Mk II Bridge over the Canal du Nord at Marquion, France, in 1918.

Increasing vehicle loads led to the development of the Inglis Mark III in the early 1940s, where the trusses were doubled or tripled, to raise the carrying capacity. At this stage, the top transverse members were removed to allow taller vehicle traffic. The lateral restraint to the trusses was replaced by inclined outriggers, bolted to short cantilevered extensions to the deck transoms.

The 1943 newspaper article in Figure 1 shows that the use of Mark III bridges for training continued well into World War 2 (WW2).

Figure 5: Inglis Mk II Bridge as a mobile bridge in WW2

6. Bridge at Simpsons Reserve

Figure 6: Entrance to of Simpsons Scenic Reserve with a vehicle coming off the Inglis Bridge

Simpsons Reserve Bridge is located 2 kilometres (km) north of Hunterville on State Highway 1, and then a further 2 km along Murimotu Road.

Simpson Scenic Reserve encompasses 38 hectares and protects an outstanding area of lowland podocarp forest that is a rare survivor of a vast forest burned off by early Pakeha settlers when they began establishing farms. The Reserve's public opening was celebrated in 1933 and included performance from the local Scots Pipe Band.

The bridge spans the Porewa Stream, a tributary of the Rangitikei River, whose confluence is east of Marton. Vehicle access to the reserve was initially a wooden beam bridge. The replacement steel Inglis Bridge was erected in 1985 because the condition of the wooden bridge had deteriorated. The Inglis Bridge was assembled by Project Employment Programme workers under instruction of the Rangitikei County Council, using components supplied by the Council. In 1995 management of the Inglis Bridge transferred to the Department of Conservation.

The history of the bridge parts prior to 1985 is not at present known.

Figure 7: Inglis Mk III Bridge in 2014

A possible earlier use of this road bridge was on State Highway 34, across the Rangitikei River at Vinegar Hill. The end span on the left of the Figure 8 looks very like an Inglis truss. This span was later replaced with another steel truss, before the old bridge was finally demolished in the mid-1970s. Tracing the history of a particular bridge is difficult because the modular Inglis concept allows interchange of components.

Figure 8: Rangitikei Bridge at Vinegar Hill from Scally, *Hunterville & District*, undated picture

It may be that when the Bailey Bridge superseded the Inglis as the popular modular military bridge, the British Army disposed of their stock of Inglis Bridge parts. Somehow they found their way to the Rangitikei County Council (and maybe other councils around New Zealand).

7. Technical Details

The beauty of the Warren truss lies in its simplicity. It is statically determinate, with no redundant members. The hollow pipe section, in our case a 110 mm ($4^3/_8$ inch) section for the main truss and 76 mm (3 inch) section for the lateral truss, is very strong in tension. The top chord members, which will always be in compression, are at risk of buckling if the length exceeds the critical length. This particular truss, probably a Mark III, has no lateral members between the trusses, but relies on the outrigger members to restrain the top chords from buckling.

Figure 9: Detail of top chord joint on Inglis Bridge 2014

The pipe members are connected with pin connections at cast iron rosette shaped nodes (Figure 9). The design of the main trusses avoids fiddly nuts and bolts, a characteristic shared by Bailey bridges. Instead, a 40 mm ($1^1/_2$ inch) pin fastens the ends of the chord into the rosette. This makes for quick assembly, and also minimises the number of small parts which can easily be lost.

The use of cast iron for the nodes is a reflection of the age of its invention. Cast iron is weak in tension, but strong in compression. The rosette allows up to six members to be connected without eccentricity. The member loads are maintained as pure tension or compression, without the bending moments often introduced in conventional truss structures. The cast rosettes would have been relatively heavy to carry by hand, but they are robust and interchangeable. The top chord rosettes have six available sockets and the bottom chord rosettes have four, with the base of the rosette bolted to the transom girders.

The crenellated collars on the ends of the pipe members are threaded connections of the hollow pipe onto the shaft that receives the pin. The collars would probably have remained attached to the chords during transport.

As shown in Figure 9, the two brackets below the collars allow the connection of the outrigger members. These appear to be fabricated out of heavy steel plate.

It is heartening to discover such a venerable example of military engineering still carrying vehicles in 2014. Its durability is testament to the versatile design by Charles Inglis, allowing repeated dismantling and erection using very simple techniques. The fact that the components probably lay in a Council yard for up to five decades, but were able to be quickly put into use, demonstrates the simplicity and longevity of the concept.

8. Conclusion

The Inglis Bridge was an important portable bridge design used in WW1. Charles Inglis, the designer, had a distinguished academic and military engineering career. Only a handful of examples of Inglis bridges are known to remain, in England, Wales, Canada, Germany, and Pakistan. The Simpson Reserve Bridge is one of the last to remain in vehicular use.

9. Acknowledgements

Much of the background history of Inglis and his portable bridges comes from three key websites on this topic: Wikipedia, the British Imperial War Museum, and Think Defence.

Jim Mestyanek, Senior Project Engineer of Manawatu District Council, assisted with the history of the road bridge at Vinegar Hill.

Richard Nester, of the Department of Conservation, was the first to identify that the Simpsons bridge had a heritage interest.

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THREE NEW ZEALAND ENGINEERS IN COLONIAL VICTORIA - BREES, HOLMES, AND RICHARDSON

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Abstract
In early 1853 in Victoria, Australia, three engineers: Samuel Charles Brees (1810–1865), George Holmes (circa 1822–1877) and Edward Richardson (circa 1831–1915) came together in the design and construction of "Brees Bridge," a large Howe through-truss timber road bridge over the Maribyrnong River at Keilor. These engineers are well known in New Zealand: Brees as engineer/surveyor/artist for the New Zealand Company 1842–1845 and Holmes and Richardson as the contractors for the very significant Christchurch to Lyttelton Railway line and tunnel, 1861–1867. But their engineering work in Victoria is not well known. In 1853, Brees was briefly the first Colonial Engineer, and between 1853 and 1861, Holmes and Richardson were the contractors for many significant engineering works in Victoria: the first large laminated timber arch bridge (Johnston Street); the first large iron box girder railway bridge (Maribyrnong River); and other works (Yarra River Wharves, South Yarra Waterworks, Essendon Railway, and Brighton Railway). This paper explores the interrelationships between these engineers and their contemporaries, describes their significant engineering works, and fills some biographical gaps about their lives in Victoria.

1. Introduction - Colonial Victoria 1851–1861

To understand the contributions that engineers Samuel Charles Brees (1810–1865), George Holmes (*circa* 1822–1877) and Edward Richardson (*circa* 1831–1915) made to Victoria, Australia, we need to have an understanding of the changing social, economic and political environment of early colonial Victoria.

Before the gold rushes, and separation of the "Port Phillip District" from New South Wales (NSW) in 1851, progress on building 'permanent' roads and bridges was slow and lengthy, with long administrative approval processes going backwards and forwards from Melbourne, through Sydney, and to London. As soon as the gold rushes commenced in Victoria, roads and bridges to service the rapidly rising population, and the shifting goldfields, were urgently needed. The existing arrangements failed. New administrative and contractual arrangements were necessary for the new Colony.

Following major floods in 1852, and a Victorian Parliamentary Select Committee on *"Roads and Bridges"*, a Central Road Board was established for main roads, and separate District Road Boards were established for parish or cross roads. To expedite construction, many concurrent separate contracts were let for sections of the same main roads, which meant many inspectors and administrators to supervise the arrangements. It wasn't too long before tolls were imposed, and later the responsibilities for main roads and bridges were delegated to the District Road Boards, to decentralise the administration further. However, government funds were still needed for major works, so a well skilled centralised overview administration was required. These processes were again fraught with problems and further reviews were needed. The 1854 Parliamentary Commission on *"Internal Communication of the Colony"* gathered evidence and made recommendations that helped set in place necessary changed administrative and legislative frameworks and processes.

As the colony developed, and society's needs changed, other works such as water supply, gasworks and railways were also needed and similar delegated and centralised administrative processes were established.

Private companies were able to raise funds for projects, provided they could get government approval and a supporting Act of Parliament. Many private railway and waterworks companies were floated, but raising funds for large projects, such as the major trunk railway lines needed for the colony, was difficult if not impossible.

The financial collapse in England and Europe, that had followed the railway boom, meant that only governments could secure funding for large projects. The 1857 Parliamentary Select Committee on *"Railways …"* recommended that the colonial government take over the role for main trunk lines of railway (Melbourne to Mount Alexander, Melbourne to Geelong, Geelong to Ballarat), leaving secondary lines, such as suburban private railway companies to fend for themselves. To expedite main line railway development, the staff from the former companies moved to the department, and many concurrent separate contracts were then let for sections of work on the same main railway routes. This meant, many inspectors and administrators to supervise the arrangements, and again these processes were fraught with problems, leading to the 1860 Parliamentary Select Committee on the *"Railways Department."*

More major floods in 1861 and 1863 again caused major damage to infrastructure and further demands and strains on Government funds and administrative processes, leading to another cycle of reviews and changes. By then our three engineers had left Victoria.

As we examine the key engineering works associated with these engineers, we will delve deeper to see the roles they played in these events, and the influence of them on their lives.

2. Samuel Charles Brees, Colonial Engineer

On 25 January 1853, Brees was appointed to be the first (acting) Colonial Engineer for the Colony of Victoria [1] by William Lonsdale (1799–1864) [2], acting Lieutenant Governor of Victoria.

Brees had landed in Melbourne on 2 September 1852, with his family, having emigrated on the first voyage of the steam-ship *"Australian"*. [3] [4]

Brees was described as *"late of the London and Birmingham Railway, Principal Engineer of the New Zealand Company, Executive Engineer of the East India Railway, &c."* [5] and the author of many *"Engineering Books"* and *"Illustrations of New Zealand*"**.**

Brees was born in Bloomsbury, Middlesex, England 29 May 1810, [6] the son of Samuel Brees and Susanna James. [7] He was probably trained as an engineer, surveyor and architect in London where he submitted a design for a village church that won a gold medallion from the *Society of Arts* in 1830. [8] He married Ann Taylor Jones on 25 June 1833, at St. John of Jerusalem Church, in South Hackney London. [9] From 1832 to 1837 he exhibited topographical drawings at the Royal Academy and he entered the competition for the design of the Houses of Parliament 1835.

In England, Brees is best known as an author of early railway engineering books. In 1837 *"Railway Practice: a collection of working plans and practical details of construction in the public works of the most celebrated engineers ..."* was published by John Williams. [10] This book included specifications and details about the works of Vignoles, Landmann, Brunel, Walker, Macneill, and Stephenson, and the London & Birmingham Railway that was nearing completion. It was a *"compilation that would serve as an exemplar for aspiring railway engineers."*

This book also included Samuel's artwork *"View of North Church Tunnel, London & Birmingham Railway"* as its frontispiece, an original of which is in the State Library of Victoria. [11]

In 1838, a second edition of *"Railway Practice …"* with corrections and additions was published, [12] followed in 1839 by an *"Appendix"* [13] that included evidence on the Birmingham & London and Greater Western Railways, and an illustrated glossary of engineering terms. In 1840, a third edition of *"Railway Practice ..."* was published [14] followed in 1841 by a separate *"Glossary of Civil Engineering…".* [15] Brees also self-published a series of architectural drawings *"The Portfolio of Rural Architecture…".* [16]

In the 1841 Census, he was a Civil Engineer, aged about 30, living in St.Pancras with his wife Ann, also about 30, and two sons, Harold and Alfred (aged 3 and 1 respectively). [17]

For three years, from 1842, Brees was in New Zealand with his family, as the principal surveyor and civil engineer, working for the New Zealand Company, and for Colonel William Hayward Wakefield (1801–1848). Brees's life and work in New Zealand is generally well documented in New Zealand biographies. [18] [19] Among other work, he was responsible for the first land surveys for the Port Nicholson conveyance, including working closely with the Maoris in surveying the land and 'reserves for the natives'. [20] [21]

In 1845, Brees is listed as the Engineer-in-Chief in the £1,200,000 prospectus for "The Oxford and Salisbury Direct Railway", [22] as well as working as a surveyor and architect, [23] and working for the New Zealand Company in England. [24]

Following his period in New Zealand he published *"Pictorial illustrations of New Zealand,"* in 1847, [25] a *"Map of New Zealand, the Island of New Ulster and the several harbours …"* [26] and *"…the Panorama of New Zealand…"* 1849 [27] all by *"the late Principal Engineer and Surveyor to the New Zealand Company".* The *"Panorama.."* also became a major painted exhibition at No.6 Leicester Square, promoting both New Zealand and Brees.

Brees's role as the *"Executive Engineer of the East India Railway Company"* still needs more research.

In 1847 another edition of *"Railway Practice"* was published; a second edition of *"Appendix"* and a fourth series of *"Railway Practice"* was published - the latter including French Railways. It was common practice at the time to republish European texts in English - such as those by John Weale, and Robert Scott Burn. By now Brees's *"Railway Practice"* was a series of four volumes. [28]

It appears that in 1846 Brees also produced *"An Introduction to the present practice of Surveying and Levelling ..."* [29] and in 1849 *"The Student's Guide to the Locomotive Engine ... ".* [30]

An enlarged edition of his 'glossary' was published in 1852 as "*Illustrated Glossary of Civil Engineering …"* [31] and republished in 1853. [32]

In 1851, Samuel Charles Brees, aged 40, is listed as a Surveyor, living in Glebe Lands, Mitcham, Surrey, with his wife Ann Taylor Brees, aged 39, and children: Harold 13 (born Holborn), Alfred 11 (b. Finchley), Edgar 9 (b. St.Pancras), Alice 7 (b. New Zealand), and Emma aged 2 (b. Mitcham). [33] A son Oswald was born in 1851 in Croydon, [34] but died in Brighton, Victoria, aged 15 months. [35]

In 1851, Brees published *"A Key to the Colonies, or, Advice to the Million on Emigration …"* [36] This 104 page pamphlet includes: a Dec 1849 review by *"The Times"* of his exhibition 'Panorama of New Zealand'; many personal 1841 'testimonials' from eminent engineers (Stephenson, Locke, Macneill, Buck, Landmann, Twynam, Cressy, Kendall); and a list of all his books. How this egocentric work was received in England or in Victoria is not known, but its contents appears to have put some colonies 'off-side'. So when he arrived in goldrush Victoria in September 1852, Brees was an 'open book'.

From 1836 until Victoria gained separation from NSW in 1851, it was governed from Sydney. For most of this period, from 1838 to 1846, the Governor was Sir George Gipps R.E. (1791–1847). [37] In September 1839, Charles Joseph La Trobe (1801–1875) [38] arrived in Melbourne and took up the new position as the Superintendent of the Port Phillip District, reporting to Gipps, who in turn reported to London.

In October 1844, David Lennox (1788–1873), [39] who had been the Superintendent of Bridges in NSW since 1832, was despatched to Melbourne to erect Princes Bridge over the Yarra River. (Figure 1) This bluestone and granite bridge, with a 150 feet central arch, a low rise of 24 feet, and with a total bridge length of 250 feet [40] completed in 1851, was built under his sole supervision, and was equal to any single-arch stone bridge in Great Britain. As Lennox later described it, for £19,000 it cost *"less than any work of a similar description in the Mother Country, as an instance of which I may adduce the expenditure of Gloucester Bridge (which is of a like nature to the one under notice), namely, £43,500".* [41] Lennox's role had quickly expanded to encompass being the superintendent of Roads, Bridges, Wharves, and Jetties, across the whole district of "Port Phillip".

Victoria formally separated from NSW on 1 July 1851, La Trobe became Lieutenant Governor of the Colony, and very soon afterwards gold was 'discovered', and the gold rushes began.

Figure 1: Opening of Princes Bridge, 15 Nov 1851. Commemorating the arrival of Separation. [42]

The enormous influx of immigrants that followed the gold, strained all the infant colony's resources and infrastructure.

Victoria may have gained separation, but the progress towards a representative government, a constitution and self-government was not swift. Initially, only substantial property holders elected 20 of the 30 members of the Legislative Council, and the Lieutenant Governor the rest, with the Governor in NSW appointing Victoria's Ministers.

In March 1852, *"The Argus"* editorial was predicting *'Starvation at the Diggings'* describing the poor conditions of the main road and bridges between Melbourne and the Mount Alexander goldfields and foreboding the dire prospects of feeding and servicing the 40,000 diggers there during winter, concluding that: *"From the first discovery of the gold-fields our incessant cry has been 'police, police, police;' we still say 'police', but we also say 'bridges and roads, bridges and roads, bridges and roads'".* [43]

Almost on cue, the long drought broke in May 1852 with an unprecedented storm lasting two days, flooding settlements, drowning many, and destroying bridges and roads across the whole Colony. [44] [45] The cost of moving goods from Melbourne to the goldfields rose to an extraordinary rate of £90 per ton! [46]

The November 1852 Victorian Legislative Council Select Committee on *"Roads and Bridges",* [47] dominated by rural M.L.C.s, was critical of the state of affairs and the administrative arrangements. The Committee noted that:

"About seventy Timber Bridges have … been erected in the Interior, at a cost varying … from £15 to £1500. : Many … have been swept away,

and those that remain are almost all of so faulty a construction, … to render it more than probable that they will share the same fate, when washed by floods at all beyond the ordinary height. And … as many as seventy additional Bridges are now urgently required for dangerous crossing places in the Interior. It appears … that the chief cause of the insufficient number and imperfect construction of these Timber Bridges may be found in the smallness of the sums voted for the construction of these indispensable Public Works".

They were also critical of bridges with piled piers that had been damaged or washed away when logs had built up against the piers during floods.

They also noted that from Returns on the table of the House, from the formation of the Colony in 1848 to 30 June 1851, £36,655-5-9 had been expended on Roads, Streets and Buildings, of which nearly £20,000 was expended in Melbourne on Prince's Bridge. [48]

The Select Committee recommended a Central Road Board with a system of independently established decentralised District Road Boards, and that all roads and bridges should be tolled.

By now Lennox must have been feeling the criticism and the enormously increased work load. He retired in 1853, aged 66. Having served for more than 21 years in his role as Superintendent of Roads and Bridges, he was entitled to a pension, and sought and was granted a gratuity of £3,000 for his extra services in Victoria. In 1853, Robert Hoddle (1794–1881), the Surveyor General, also retired (or was eased out), and Captain Andrew Clarke R.E. (1824–1902) [49] took over the position.

Brees's 'acting' appointment in 1853 appears to have been a 'stop-gap' between the resignation of Lennox, Superintendent of Roads and Bridges, and the arrival of a person with broader management skills to take up and service the rapidly expanding duties and role of Colonial Engineer.

Brees's successor, Captain Charles Pasley R.E. (1824–1890), [50] a military college contemporary of Captain Andrew Clarke R.E., was appointed in England on April 1853, and would arrive and take up his position as Colonial Engineer on 20 September 1853. [51]

The parlous state of affairs in Victoria is easily seen in Brees's *"Statement of money expended from various votes for public works from 1st January to 31st December 1852"* [52] (the period before Brees was in office) presented to Parliament in August 1853. Less than half the £20,000 voted for Roads, Bridges, and other works had been expended, and most of the spending priorities were on access tracks to the goldfields. Labour and materials had become expensive and hard to procure.
Brees may or may not have had the necessary skills to handle the enormous task, but either way, he had landed himself in a 'no win' situation.

3. Brees Bridge 1853

Figure 2: 'Keilor Bridge' Watercolour of 'Brees Bridge' by Samuel Charles Brees. [53]

Nevertheless, during his very brief time as acting Colonial Engineer, Brees did achieve some things, notably 'Brees Bridge' over the Saltwater River (Maribyrnong River) at Keilor. (Figure 2) This was a most impressive pioneering bridge with high stone abutments, in a gorge setting, with steep winding approaches, on the main road from Melbourne to the Mount Alexander goldfields. The *"river rises here in floods to thirty feet or more above the bed of the river"*, and *"the traffic on the road exceeded that of any road in England, and yet no provision was made for a crossing, several old structures being washed away."*

Apart from Lennox's stone arch 'Princes Bridge', all other bridges in the colony had been constructed in timber. The longest being the many span timber bridge over the Barwon River on the road from Geelong to Port Fairy, with a total waterway crossing of 190 feet. [54] [55]

The 'Brees Bridge' comprised three large 'Howe' patent through-trusses 160 feet long, and 17 feet high, with a clear span of 135 feet, on 38 feet high stone abutments *"the outside courses being hammered and dressed, and the hearting of rubble masonry".* The superstructure of the bridge consisting of two 10 feet 6 inch carriageways between the trusses, on a deck supported on the truss bottom chords. The contract for the "Mount Alexander Road, Keilor Bridge", Stone Abutments and 160 ft Howe Truss was awarded to Thomas Oldham and others, for £11,383-0-0 in March 1853 with a December 1853 completion. Unfortunately Oldham became insolvent and the erection was completed by the Central Road Board, with George Holmes C.E. Engineer being paid £400. [56] The works were finally completed in

April 1854, with the total cost of the whole crossing being about £20,000.

Holmes had been working for the Central Road Board, in February 1854, when he was paid by Treasury for house rent, so it appears that he was still working for them when he took charge of completing the Keilor Bridge. [57]

The manner of construction of the bridge is described in a paper *"The Keilor Bridge"* presented on 7 June 1855, by Richardson, also an engineer for the Central Road Board, to the Victorian Institute for the Advancement of Science (VIAS), then in its first year. VIAS later merged with the Philosophical Institute of Victoria, and became the Royal Society of Victoria. [58] [59]

"At the time … there were only two contractors in Melbourne considered competent to undertake the work, one of these being the successful tenderer…" [Oldham] *"… being a gentleman of great practical attainments, undertook to build the trusses according to his views, although repeatedly advised by the engineer* [Holmes] *to the contrary."*

Oldham was a very experienced railway contractor prior to arriving in the colonies, but seemed unable to adapt easily to the colonial conditions, or to new ideas.

"When the work was commenced, the only suitable timber that could be obtained was four large pine logs; the material had been collected from all sources, chiefly from New Zealand." And in discussion, Richardson noted that *"Kaurie [sic] pine had the same property as English oak of shrinking whenever it was cut, even although it had been previously seasoned."*

The trusses were first framed on the ground, then set on edge, then rotated 60 degrees to align then with the axis of the bridge, then launched across the abutments on edge. *"This was an undertaking of no small mechanical skill, and is worthy of the man who projected the plan. A truss of 17 feet high, 50 tons weight, and 160 feet long, to be moved across a chasm 100 feet, even with English means, would be considered no mean undertaking".* The first truss was successfully launched with no problems, but an accident occurred after the second truss had been raised on edge, and was being launched, the balance was lost and that portion of the structure fell to pieces. Five men were under the truss when it fell, but fortunately they escaped by passing through the apertures.

"The case being one of great difficulty the Government allowed the contractor to proceed with the work until this truss was rebuilt and carried over, on the condition that the resident engineer [Richardson] *was responsible for the completion of the work. This being the first time the engineer was allowed to interfere with the arrangements or mode of carrying on the works."*
"… the engineer, Mr. George Holmes, previously expressed his dissatisfaction as to the plans proposed for erecting the bridge, his own notion being to erect a temporary pile scaffolding, and on that to erect the truss, but … taking the position of the broken truss, it was thought advisable to conform to the contractor's views and assist him - … the second truss was launched safely and placed in its position without incident."

Richardson noted that *"… particular attention to details is often of more importance in the stability of a structure…"* and *"as an instance, a design by the engineer* [Holmes], *of a clamp … proved its efficacy in the broken truss, the truss was broken in three places, but in no instance where a joining of beams took place did the clamp give way".*

The third truss was, by Richardson's instructions, *"built on a platform resting on the two trusses previously carried across, and in one third the time and expense taken to place either of the others in its position, which evidently proves the suggestion of the engineer in the first instance, that is, to build the bridge on a platform".*

During discussion, Thomas Ellis Rawlinson C.E. (1823–1882) noted that a similar accident to that with the truss as Keilor, had previously occurred in Liverpool, England.

The 'Brees Bridge' appears to be the first large 'Howe' truss bridge to be built in Australia. Howe patent trusses (Figure 3) were the first 'composite' trusses, modified from 'Long' trusses, with vertical iron rods used between the top and bottom chords, instead of timber. [60] At Keilor, the end bays at each end appear to have had timber verticals, to strengthen and stiffen the truss at the abutments.

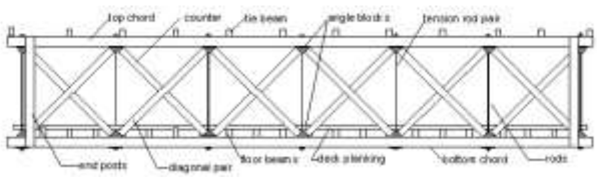

Figure 3 Diagram of Howe Truss. [61]

Richardson stated that the quality of the workmanship would compare well against similar constructions in Europe and America, and suggested that *"if this bridge were enclosed and weather-boarded, it would last thirty years".*

The mutual respect established between Holmes and Richardson, when working together on 'Brees Bridge', set the foundations for their enduring 23 year partnership.

Within a few months of the completion of the bridge, the Act was passed that enabled District Road Boards and the Central Road Board to collect tolls on bridges. So a toll house was built for the Keilor Bridge.

Although the bridge served the gold rush traffic well, the huge volume of traffic and the climate also took its toll on the bridge. Pine timber exposed to Australia's weather rapidly deteriorates, through moisture, rot, fungus, or insects - droughts and flooding rains accelerates the decline.

The terrible floods in 1861 and 1863, damaged or destroyed many bridges. The damaged ones were 'temporarily' stabilised, repaired or strengthened with timber props or struts. Ironically, in 1863 the full responsibility for bridges and tolls had been transferred to the District Road Boards. After the floods they all had difficulty, and sought funds from government for repairs or replacement.

By 1865, the notable, and accurate, colonial artist Eugene von Guerard sketched the Keilor bridge. [62] His sketches show that the bridge trusses had been: propped by a central pier; propped on the left bank by many short diagonal struts and the left masonry abutment was covered in earth to combat erosion; propped with a few diagonal struts from the right masonry abutment; and some weather protection in the form of small roofs had been added over the tops of the three trusses. The newspapers in 1866 confirm the sad state of the bridge depicted in von Guerard's sketch – half of the bridge was closed, and it needed major maintenance work or replacing. [63]

A temporary replacement bridge was built in early 1867, and on 21 November 1868, a new 'tubular' iron bridge, built for the Keilor District Road Board, was opened, replacing the timber Howe trusses. Newspapers provide very detailed descriptions of the bridge, and the opening festivities. [64] The new bridge was also a through bridge. The wrought-iron box girders were 142 feet long, spanned 136 ft between the old bluestone abutments, that were raised 3 ft 11 in, with one roadway 20 ft wide and 45 ft above the summer river level, 6 ft 6 in above the flood levels. The old abutments were in poor condition, the one *"on the left bank had to be taken down altogether, and an entirely new one erected in its place. The one on the right bank of the river had also to be taken down to the depth of six feet",* meaning only the top 6 feet. The stones from the condemned left bank abutment were used to protect the new abutment from erosion. [65] The engineer for the new bridge work was Edwin Brown (1812–1879) and Son, Camberwell, and the contractor was Enoch Chambers, the whole work costing £6,000. The bridge became known locally as the "Basket Bridge" because of its mid-span handle-like upper-chord lateral-bracing.

The bridge deck was repaired in 1926, the curved 'handle' bracing was replaced with a squared steel brace in the 1950s, and the bridge was taken out of service in 1964 when a replacement bridge on a new alignment was opened. [66]

Today the 1868 box iron girder bridge, still stands on the repaired 1853 bluestone abutments, and is used as a pedestrian bridge in the Maribyrnong valley parklands. It is of state significance, is included on the Victorian Heritage Register, [67] and is technically significant for the structure of its box girders that have two smaller boxes or cells forming the tops of the girders. [68]

4. Samuel Charles Brees – after 1853

History has not been kind to Bree's brief period in Victoria. Many histories have misinterpreted the "failure" of the contractor in erecting one of the Howe trusses, to be a total collapse of Brees Bridge, and hence a fault wrongly attributed directly to Brees. His short stint as acting Colonial Engineer and his departure have often been misread as a 'dismissal', when his position was clearly just a 'stop-gap' before Pasley arrived.

Brees's role is cast further into the shadows by the biographies of his successor, Pasley. *"His department, hitherto undermanned and demoralized, soon busied itself with port improvements and with the building of barracks, court-houses and offices throughout the settled districts."* [69] *"Pasley very quickly had many plans drawn up, including plans for Parliament House £250,000, and for Government House £90,000."*

After Brees had left the position, murmurings about him were aired in Parliament, and it was purported that some evidence was gathered, but the complaints appear to have come to nothing. [70]

Brees's family may have left Melbourne in September 1853, on the *'Roxburgh Castle',* although in October 1853, it appears that Brees was still living in Brighton, selling his books. [71]

Brees may have been in Bendigo for a while. He was living in Sydney between 1860 and 1865, where he spent his later working life as an artist, surveyor, engineer, and architect. His artwork, newspaper letters and articles about his drawings, paintings, surveying, engineering, architecture, and about his prior experiences in New Zealand provide evidence, and a picture of a busy man. He held an exhibition of 60 framed artworks in Sydney in August 1861, [72] and, in 1862, he joined his architect and artist son Harold in an "Architectural Gallery".

In New Zealand and Sydney, Brees is known for his many works of art, which are scattered in galleries and private collections. His drawings were used as the basis of many published engravings, along with descriptive text about the places he visited. His portfolio of artistic work and his biography as an artist is becoming better documented, but is still incomplete. [73]

Brees died on 3 May 1865, aged 55, on board the ship *"La Hogue"* in East India Dock, Blackwall, London, having just arrived from Sydney. [74] [75] His Probate (Effects under £20) was settled in 1868, his wife Ann was then living at Fortress Green, Finchley, London. She died on 1 October 1882, at 6 Myrtle Terrace, Turnham Green, London. [76] [77] Many of their children married and stayed in NSW, his eldest son Harold dying there in 1904, and son Edgar in 1917.

5. George Holmes and Co.

The design and successful erection of the Howe truss bridge over the Saltwater River, can almost certainly be credited to Holmes, using skills, knowledge and experience he had gained working in North America. Edward Richardson who had lived and possibly also worked in North America, contributed.

Within the firm "George Holmes and Co.", Edward Richardson is the *"… and Co".* Sometimes the firm is mentioned as "Holmes and Richardson". Early contracts were awarded just to "George Holmes" so more research is needed to determine when the partnership actually commenced.

George Holmes was baptised at St Pauls' Church of Ireland, Newtown Forbes, County of Longford, Ireland on 23 Aug 1822. [78] His father was Alexander Holmes, a carpenter, and his mother Elizabeth. George was one of their six known children.

Alexander and family are said to have emigrated to Canada in 1846, where they settled at Huntley, Carleton County, Ontario. It is not clear if George went with the rest of the family. He is not in Huntley with the family in the 1851 Canada Census, where Alexander's occupation was recorded as 'carpenter', and son John was as 'B.Surveyor' (building surveyor?). [79] In the 1871 Census for Huntley, Alexander's occupation was 'farmer' [80] although in George Holmes' death certificate it was 'architect'. [81] Many builders designed as well as built houses, so it is not an unreasonable claim.

When giving evidence to the 1854 Parliamentary Commission enquiring into the best mode of providing for the *"Internal Communication"* of the colony, Holmes stated that he was a Civil Engineer who had worked in England, Scotland, the United States and Canada, and had been in the colony for about 18 months, arriving about November or December 1852. He had experience road making in England and Canada, and had been employed by the Central Road Board of Victoria for 14 months, but was now in private practice as a contractor. [82]
At a later enquiry on the *"Railway Department"* in 1859-60, [83] Holmes said that he had worked in Brunel's office for several years, probably in the period just before 1848, when he left England for the USA. On the passenger list for the *"American Eagle",* which departed St Katherine's Dock on 28 September and arrived in New York on 3 November 1848, were George Holmes, aged 27, engineer, and Margaret Holmes, aged 20. [84]

In the 1850 Census of New York State, George Homes (sic), 29, engineer, Margareth [sic], aged 21, and George H, 11 months, were residing in the City of Buffalo, County of Erie, State of New York. [85] Both George and Margaret are stated to have been born in England, and their child in New York (confirmed by his death certificate, which stated his birthplace to be Buffalo). [86]

Holmes, civil engineer, was listed in the *"Buffalo City Directory"* in 1850–51 and 1851–52, residing at the corner of Virginia and Niagara. [87] Before the next directory was due to be compiled, George, Margaret and their infant had packed their bags and departed for Melbourne. They are probably the 'G Holmes, wife and child', unassisted passengers on the *"Epaminondas"*, arriving in Melbourne in November 1852. [88]

Edward Richardson was baptised at St Paul, Canonbury, Islington, England, on 13 February 1831, [89] the son of Richard, a ship broker, and Elizabeth Sarah. Richard and Elizabeth Sarah Miller married by Banns at Christ Church, Southwark, England, on 14 October 1820. [90]

The family believes that the Richardsons immigrated to Canada in 1831, joining Richard's younger brother Hugh, who was a sea captain and ship owner. Richard was the first bank manager of the London, Ontario branch bank of Upper Canada. Richard died in London, Ontario in 1838, leaving a wife and seven children. Edward was educated in London, Ontario with his siblings and cousins (some New Zealand biographies inaccurately say London, England). His cousin Edwin Richardson was also a railway engineer, and may have worked with Edward in Australia and New Zealand. [91]

Richardson commenced his engineering career as a pupil under the resident engineer of the London and South Western Railway in 1845, after fulfilling his apprenticeship, he was for some years engaged in the locomotive department of the Great Southern and Western Railway of Ireland. [92] [93] [94]

The only arrival in Victoria of an E Richardson that matches his supposed arrival in Melbourne in 1852 is that of the unassisted passenger

"E[d]. Richardson" who arrived on the *"Great Britain"* from Liverpool via the Cape of Good Hope in November 1852. [95] No further details have been found to confirm this.

Edward Richardson married Margaret Higgins, second daughter of the late John Higgins, Esq., of Sligo, Ireland, on 13 May 1856, at St. James's Cathedral, Melbourne, by the Very Rev. the Dean, and afterwards at the residence of Patrick Higgins, Esq., Moonee Ponds, by the Rev. Matthew Downing. [96] [97]

Patrick Higgins was an uncle of Margaret. He was also a contractor, and his name is recorded against many contracts in Victoria. In May 1866, he was awarded the contract to build the Great Zig Zag Railway in NSW 1866–1869. This significant section of railway consisted of seven stone viaducts, varying in height from 10 to 70 feet, three tunnels, and nearly one and a quarter million cubic yards of excavations, two-thirds through rock.

Edward Richardson also had relatives in Victoria - an uncle William Marsh Miller, was an estate agent and later the first Town Clerk of Essendon.

Richardson and his wife, lived in Essendon, had two sons, Edward (born 23 March 1857 [98] [99]) and John Patrick (born 25 May 1858 [100] [101]), but John died an infant on 22 February 1859. [102] [103]

Edward Richardson, George Holmes and William Marsh Miller were all trustees of the St Thomas' Church of England, Essendon before 1862.

The period from 1852–1853 was a desperate time for the infant Colony. Victoria urgently needed infrastructure but the many private railway, bridge, and water companies that were floated were unable to get finance, and even though Governments could secure finance through guarantees, labour shortages meant higher prices, and plans for capital works were not able to be achieved.

Furthermore, private companies operations were usually design, construct and operate practices where expedience was important, compared with the very different operational needs and scrutiny of Government practices.

Many engineers, contractors, and speculators had immigrated to Victoria in the wake of the goldrush, in anticipation of boom times. But the lack of private capital and self-government administration systems meant they often had to be versatile, do other things, bide their time, and network with as many influential people as possible.

Engineers' training and skills in surveying, drawing, sketching, architecture as well as engineering and management could all be gainfully employed. At the time engineer Edward Dobson (1816–1908) [104] advocated that an *"engineer should endeavour to attain proficiency in rapid landscape-sketching" "it is well for a young engineer … to take every opportunity of graphically illustrating his reports, as a means of inspiring the confidence of his employers in the ability of their engineer".* [105] Engineer Edward Snell's diaries [106] describe the life of an engineer at this time in Victoria, and we know that Brees is remembered more for his artistic and writing abilities than for his engineering works.

From articles, advertisements and letters in newspapers, from submissions to Parliamentary committees, from notices in the Government Gazettes and from discussions and proceedings of learned societies, that both Holmes and Richardson were actively networking.

These were changing times. In December 1854, the organised rebellion of gold miners at Eureka Stockade in the Ballarat goldfields happened. By then, La Trobe had left, and his unpopular replacement Captain Sir Charles Hotham R.N. (1806–1855) [107] had arrived. In March 1854, the constitution, drafted by Andrew Clarke, was approved by Council. It gained Royal assent in July 1855, but it was not until November 1855 that Victoria was self-governing, and another year until the first elected Victorian parliament sat, in its new Parliament House.

Many new cultural and learned societies were established at this period, including the Philosophical Society of Victoria, and the VIAS. Almost from its commencement in 1854, "George Holmes, C.E., Engineer of Water Works", was a member and Councillor of the VAIS. Council members included the governor, Charles Hotham; the Attorney General, George Higginbotham, engineers Andrew Clarke, Charles Pasley, Alexander Kennedy Smith, and Matthew Bullock Jackson. So Holmes was networking closely with many of the key 'movers and shakers' of the period.

In May 1855, Holmes prepared a paper for the VAIS *"On the Timber of The Colony"*, [108] but in his absence, the paper was delivered by Richardson. Holmes described some of the native timbers, usually hard and tough woods, and their many uses in the colonies, including those for engineering purposes, such as *"Red and Blue gum for public works, such as railways, bridges, piles,"* and *"stringy bark … its immense size and straight grain renders it very useful where long piles are necessary".* In the Sydney Exhibition Catalogue, 245 varieties of native woods were listed and of these *"22 produce excellent hard wood, 12 produce wood suitable for turning, 16 produce wood of considerable variety for cabinet making."*

Except for comparative tests of iron bark with English Oak, Holmes was "*not aware of any experiments as to the relative strengths of timber grown in Australia,"* and he had *"contemplated a series of experiments on the relative strength of the several woods, but … had not been able to carry them out in time".*

The unusual shrinking of local timbers was noted *"most hard wood grown here, … when placed in works are much more liable to contraction longitudinally than European wood, therefore it behoves engineers, architects and builders, to make calculations accordingly. I have myself seen one-half an inch contraction in a piece of timber eight inches square by ten feet long."* Richardson noted also that soft woods *"of New Zealand shrank longitudinally, an unusual thing in England"* and that *"some Kaurie [sic] pine, used by him, had shrunk on fresh cuts being made after it had been felled two years."*

It is interesting to note that a month later, when Richardson presented his paper on *'The Keilor Bridge',* Francis Bell C.E. (*circa* 1821–1879) [109] also presented his paper on *'Wrought Iron Bridges as adapted to the Colony'*. [110] Bell and Richardson had both been engineers with the Great Southern and Western Railway of Ireland, as had Brees – Bell as a civil engineer and Richardson as a locomotive engineer. Holmes' earlier opinion about stringy bark piles may have been noted, as stringy bark piles were used in 1856 under the tall bluestone piers for Bell's Hawthorn Bridge [111], and are still in use today, nearly 160 years later.

Holmes continued his connection with the VAIS / Royal Society of Victoria, becoming a Life Member in 1857, and is listed on the Membership lists up to 1868, well after he moved to New Zealand. Richardson became a member on 8 March 1855, and is listed as a member to 1860.

Later, in December 1858, Holmes was elected a member of the recently formed Mining Institute of Victoria. [112]

As mentioned previously, Holmes was called to give evidence on many occasions before Parliamentary Select Committees. We have summarised Holmes' biographical details gleaned from these reports, but they also provide more details about his engineering skills, knowledge and works, as well as his contributions to the committees' recommendations.

In the 1854 Commission report on *"Internal Communication"* we gain the broadest and deepest understanding of the skills, knowledge and backgrounds of many of the engineers in the colony.

Holmes expressed his opinions about the best methods for road and railway construction in the colony, contrasting the difference in railway practices in England and in America – the former being expensive and the latter being built cheaper.

In America, provision for double track was made in the roadway, but by using single track, timber bridges, timber stations, level crossings, and avoiding tunnels, the initial costs could be kept down, then as the traffic increased, more permanent infrastructure could be provided. He had knowledge about the operations on the Albany New York railway, *"where twelve trains, or six each way with luggage trains at night"* on a single track line, and about the New York Erie Railway, that had more extensive works per mile than other railways. For railway works in Victoria, he suggested using 60lb rail and timber bridges and sleepers of blue gum. Then as traffic increased providing more permanent works later.

Holmes said that he had tendered for the formation of six miles of the Geelong Railway. He was asked for, and described a suggested route and estimate for the railway to Castlemaine.

For branch lines with little traffic, Holmes discussed the advantages of using lighter longitudinal planking, and lighter 'bars' where horse drawn trains or trams might be used, compared with heavier sleeper and rail construction for main lines.

In mentioned that in Canada these tram roads were used for the heaviest work, drawing timber, etc, and he discussed the operations of the Chippewa horse railway line to Niagara Falls.

He had also built plank roads in America, and described the method of diagonal planking.

Holmes had prepared an estimate for a tram road for the Plenty River (Yan Yean Water Supply) *"to be made in order to take up the iron pipes for the water works."* This tramway was built, but we have not been able to confirm his role in it.

He had contracted with the Corporation (City of Melbourne) for a portion of the north end of Elizabeth-street. the roads then being pitched and afterwards covered with blue stone metal. *"I have agreed to make a road three chains wide, and to form a metalled roadway in the centre forty feet wide; there is also a quantity of kerbing and channelling to be done. There are thirty-one chains in the whole, and I have tendered for it £10,690, being at the rate of £25,000 per mile."*

His discussion about rates of cartage shows a deep understanding of labour and the economics of the period. He indicated that labour shortages were no longer a problem. In his contracts *"I ordinarily employ about two hundred men, and I* *find no difficulty in procuring them, as there are frequently more applicants than I have work for."*

In discussion about the most efficient construction methods for a railway to Castlemaine, Holmes recommended *"the plan adopted on the New York and Erie line, on which the works were very heavy, so much so that it was thought that letting the line to one man would have delayed the company too long; so it was let out in mile sections to different contractors, and in this way was done in a very short time and well."* This recommendation, of "sectioning" of contracts, was accepted by the committee and adopted by the Victorian Railways for building the main trunk lines.

He suggested that if materials and plant were purchased by the railway company, then a contractor could build the railway more easily and cheaper. *"If I had rails to lay down and dirt waggons at my disposal, I, as a contractor, could do the work much cheaper and better, and with more benefit to myself."* This suggestion was also taken up by Victorian Railways who later let bulk contracts for materials.

Holmes suggested that if a bridge was being built, and an engineer agent in England was appointed they could *"then go to some good house and give his orders, and the firm would not for their credit sake send out bad work."* Again this suggestion became the practice later adopted by the Victorian Railways for acquiring bridges from England.

Holmes also added that he would rather see a railway *"in the hands of a private company, as they can always get the work done cheaper than a Government, either here or in any other country. A Government is always looked upon by a contractor as fair game."* But this was not to be so, and the Victorian Government Railways took over all trunk rail lines - the Geelong to Melbourne, and Melbourne to Mount Alexander railways. The suburban lines remained as private companies.

6. The Wharf Contract 1854

In November 1854, "George Holmes and Co." were awarded a contract for the extension of the wharf on Yarra River, for £80,159-5-0 comprising 696 lineal yards of wharf and paving, plus sheds, with a completion of May 1855. "George Holmes and Co." here included George Holmes, Edward Richardson, Owen Connor, and Patrick Phelan. The contract appears to have been the largest single Victorian contract awarded at the time.

Others tenderers for the work, ranged in price from £35,000 to £82,000. [113] Many assertions about the tendering process, and about who was awarded the contract were made in the press, particularly *"The Age"* [114] [115], and this lead to questions in Parliament – if George Holmes and Co. was not the lowest tenderer, why did they obtain the work? Why did the Officers of the Royal Engineers recommend it? The complaints became even more bitter, when Holmes employed some of the unsuccessful bidders as sub-contractors.

In March 1855, a Parliamentary Select Committee was appointed to *"… enquire into and report upon the acceptance of Mr. Holmes's Tender for the Extension of the Wharf at Melbourne in preference to other Tenders of less amount."* In its report, tabled in Parliament in June 1855, with proceedings of the committee, minutes of evidence and appendices, [116] we gain a detailed insight into Holmes's operations, into the state of the construction industry and of the government tendering processes at the time of the contract.

In the evidence, it can been seen that the contracting and construction practices and processes of Holmes were well ahead of the contenders, with Holmes also providing bank guarantees for completion of his work.

Pasley, Colonial Engineer, in giving evidence, unequivocally stated the reasons "George Holmes and Co." had been recommended for the work, when no comparable work of this scale had been done previously in the Colony - Holmes had more experience in timber work, in road work, and in managing large labour teams than any other tenderer, and Holmes' tender price was realistic and close to his estimates.

Pasley specifically mentioned that:

- Holmes had built the bridge at Keilor "*from his own designs, and under his own superintendence"* and that with Holmes' long experience in timber work in America "*there is no better school for timber work than the United States"* and no other tenderer had comparable experience;
- that several contracts with both the Central Road Board and the Corporation of Melbourne had been "*executed very satisfactorily and quickly."*
- and regarding labour, "*when there was a great outcry raised about distress and want of work for the laboring people, the Road Board … set to work to make several miles of road, with instructions that the contractors were … bound to employ a large number of men within a very limited time, … Mr. Holmes was one of two persons who were selected by the Road Board … being a man who had shewn that he had a good deal of energy and who would get on quickly."*

Overall, including the 29 subcontractors employed, Holmes employed about 1500 different men to complete the work, and had purchased equipment, such as a pile driver that he thought he would use on later jobs, or rent to other contractors.

George Holmes and Co. had by then successfully completed the contract. In short, the committee could find little fault with the contractor, or the work, and the many expert witnesses had few complaints about the high quality of the work. The only complaints were that variations were made to the contract, such as a macadamized roadway instead of a plank road, and the lowering of the road and wharf to match existing work. The only complaints from the wharf users were that *"the platform of the wharf has been made inconveniently wide",* but that change had been instigated by the board, not Holmes. The Committee recommended that *"the system of tendering for Public Works now in operation in the United Kingdom be adopted in Victoria"* even though it might entail additional expense.

7. South Yarra Waterworks Company 1855

In an advertisement 'South Yarra Waterworks Company' in *"The Argus"* 17 September 1855, [117] George Holmes C.E., Edward Richardson C.E., and Alexander Kennedy Smith C.E., are listed amongst the provisional directors, with the capital of the company £20,000, in two thousand shares of £10 each, with power of extension to £40,000.

A full description of the existing undertaking, completed in August 1854, is provided, as well as the proposed extensions to Prahran, Windsor and St Kilda. The basic system comprised a steam plant pumping water drawn from the Yarra River, to a tank on the South Yarra hill, and then gravity fed towards Prahran along Chapel Street, "*supplying water to the public from a fountain situate at the intersection of the Gardiner's Creek Road with Chapel-street, Prahran"* Mr William Robertson was the engineer of the Company. [118]

In January 1856, the works had been carried out, with the new tank at St Kilda Junction. The provisional directors (including Holmes and Richardson) stood down and four directors were elected for the ensuing year. [119]

Holmes tendered for the construction of Victoria's Parliament House but was unsuccessful. In April 1856, the stonemasons in Victoria achieved the world's first eight hour day. A Select Committee enquired into the effect it had on the contract for Parliament House. [120] and Holmes was called to give evidence.

8. Johnston Street Bridge 1856-1857

Figure 4: Johnston Street Bridge, photographed c1873. Constructed by George Holmes and Co., 1857, and propped after the floods of December 1863. [121]

The Johnston Street Bridge over the Yarra River, (Figure 4) was a large single span laminated timber arch bridge between tall bluestone abutments. The span was 170 feet, the longest in the colony. The abutment on the east side of the river was erected on solid rock, at an elevation of 30 feet from the level of the river, and the western side on piles averaging 25 feet in length, filled up with concrete to a depth of three feet. The height of the centre of the span of the arch from the level of the river was about 50 feet. [122] Contracts of £9,816-15-9 for the Stone Abutments, (awarded June 1856 with a completion of March 1857), and of £15,541-11-6 for the Timber Bridge (awarded February 1857 with a completion of November 1857) were awarded to George Holmes and Co. [123]

"The Argus" of 8 November 1856, describes the laying of the foundation stone for the Johnston Street Bridge on the previous day. This is the most incredibly detailed report about laying a foundation stone I have ever read – it describes everything - the people in the procession, the bands, the full details of the Masonic ceremony and all the details about the reception afterward. About 3000 people attended the ceremony, including the Provincial Grand Master, Captain Andrew Clarke R.E. M.L.C., who was presented with an inscribed silver trowel to mark the occasion. Afterwards about 400 to 500 sat down to a well provided collation at Abbotsford House, and many toasts and speeches were offered all round. These including toasts to the health of the bridge engineer, George William Harris C.E. (1819–1904), [124] to the contractor, George Holmes, and to Clement Hodgkinson, C.E. (1818–1893), the district engineer.

Laminated arch timber bridges had been recommended by the 1852 Parliamentary Select Committee on *"Roads and Bridges"*, as a way of economically constructing 'temporary' timber bridges over wide waterways, avoiding the need for piers that logs might build up against during floods and damage or wash the bridge. A plan of a timber arch bridge was appended to its report.

Other laminated arch bridges of this type were built, including road bridges on the goldfields near Castlemaine and Clunes; the 1854 railway bridge over the Yarra River (90 feet central span) on the Melbourne Hobson's Bay Railway, [125] the 1857 multi-span Studley Park Road Bridge over the Yarra River at the northern end of Church Street; the road bridge over the Merri Creek on the Heidelberg Road at Northcote; and the 1862 Botanic Gardens footbridge. A very large five span laminated timber arch railway bridge was built at Singleton, NSW. [126]

At the time of its construction, the Johnston Street Bridge was thought to be high enough above the Yarra to avoid future flood damage, but when the very large flood swept through in December 1863, [127] [128] the lower part of the timber archway was lifted and warped and it became necessary to support the bridge with timber propping. [129]

Most laminated arch bridges proved to be unsuited to Australia conditions and climate, The only surviving laminated arch bridge in Australia is at Angle Vale in South Australia. [130]

In 1876, the Johnston Street Bridge superstructure was replaced with a wrought iron bridge, awarded to the contractor William Aitcheson Shand (1823–1877). [131] The new wrought iron box girder bridge, 22 feet wide with two 6 feet cantilevered footpaths, rested on roller bearings on top of the existing bluestone abutments that were raised 3 feet, and supported on two new slender cast iron column piers designed to minimise interference with the waterway. Thus providing three spans of about 60 feet each, with the girders continuous over the piers. [132] All the iron work for the bridge was manufactured on site by Mephan Ferguson (1843–1919) [133] - a son-in-law of the contractor W.A.Shand. The design engineer for the work was Charles Rowand C.E. (1825–1908), Roads and Bridges department, with George Donaldson C.E. (1826–1903), Railways department, as assistant-engineer.

The wrought iron through-girder design might have been practical for the design of a railway bridge but together with the tight bends in the roadway at both ends, the bridge was unsuited to motorised traffic. [134] Over many years it became *"Melbourne's worst bottle-neck, and one of its worst death-traps".* [135] From 1954 to 1957, the current wider straighter re-aligned cast-in-place reinforced concrete tee-beam and slab bridge was constructed in stages by the Country Roads Board using direct labour. [136] [137] [138] [139] [140] Only the downstream half of the new superstructure and half of the western abutment could be constructed while the old bridge remained in use.

When the new concrete bridge was finally completed in 1957, one hundred years after the original laminated timber arch bridge, the wrought iron bridge, *"the museum piece at the end of an arterial thoroughfare"* was finally sent to *"a junkdealer"*.

Today, still standing in Studley Park is the solid 1856 eastern bluestone abutment, with its three angled springing points for the laminated timber arches at its base, topped by the roller bearings for the 1876 wrought iron girders, and fenced by remnant sections of the 1876 riveted lattice handrail. Largely forgotten, its man-made rock face, known by local rock climbers as 'Mt Studley', is used as a 'bouldering' site.

9. Saltwater Railway Bridge 1858

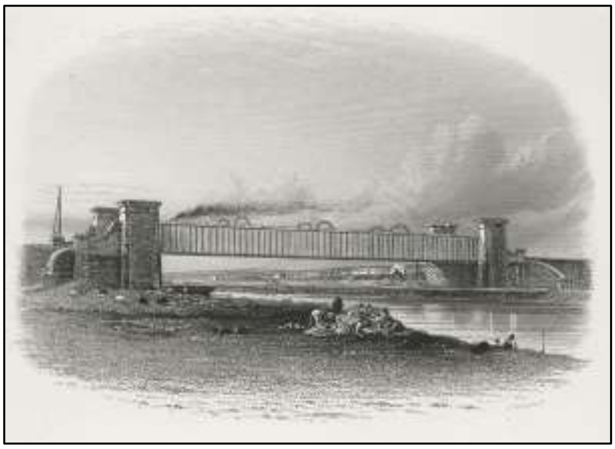

Figure 5: Saltwater River Railway Bridge on the Melbourne Mount Alexander and Murray River Railway, 1862. George Holmes and Co. contractors. [141]

The bridge over the Saltwater River on the Melbourne Mount Alexander and Murray River Railway (Figure 5) was a large through box-girder bridge, with a single span of 200 feet, and was, for more than 75 years, the longest span railway bridge in Australia. [142] [143] [144]

The *"First Report of the Proceedings of the Board of Land and Works"* 1859, [145] describes all of the works on the Victorian Railways, and details all the tenders, and contracts entered into during 1858. The following significant works on the Melbourne Williamstown Railway had been awarded to Geo. Holmes and Co.

- Cole-street, Williamstown, for the erection of the bridge, over the railway … £3,877-3-6
- Stoney Creek, for the foundations of the bridge, and extras ... £11,348-13-9
- Stoney Creek, for the erection of the 90 feet long iron girders for the bridge … £3,232-0-0
- Saltwater River, for the construction of the necessary staging, and the erection of the 200

feet long tubular iron girders, bridge, and extras … £30,331-15-6

Contractors Pierce and Dalziel were awarded the contract for building the bluestone abutments for the Saltwater River bridge, £31,737-0-0. Holmes had tendered for the work at a lesser price, as he had idle plant from the wharf contract, but was not awarded the contract. Later, in 1860, when presenting to the Parliamentary Select Committee upon *"Railways Department"* he argued that such bridge contracts should not be split, as determining blame for any faulty work could prove difficult to resolve.

In 1857, prior to being awarded the contract, Holmes had expressed his opinions about the railway company's practices and the arrangements for this bridge to the Select Committee on *"Railways".* [146] Now he had the contract, he needed to work with the former company people, now working for the Railways Department.

The 216 feet long, 15 feet high, wrought-iron box girders for the Saltwater River Bridge were fabricated in England by John Fairbairn and Sons, of Manchester, and the girders for the 90 feet Stoney Creek Bridge by Peto, Brassey, Betts and Co. The Saltwater Bridge box girder designs were significant, as they were different to the simple box girder in having two smaller boxes or cells forming the top flange of each box girder.

On 7 November 1856, Isambard Kingdom Brunel became associated with the bridge, when he was appointed as inspecting-engineer, by the Board of Trade in London, to superintend the carrying out of the works contracted with Messrs. Dalgety and Co. on behalf of the Victorian Government.

A copy of correspondence with Brunel is appended to the 1857 *"Report of the Select Committee upon Railways."* Brunel begged *"to suggest that in any future contracts, … considerable discretionary power should be left to such inspecting-engineer to modify the terms of the contracts, and particularly the mode of manufacture; the Engineer-in-chief taking care to specify in his instructions to the engineer in England, on what points, if any, he may wish a strict adherence to his drawings or specifications".*

Despite all the layers of notable engineers checking all the steps between the design, fabrication, trial erection, shipping and delivery to Melbourne, George Holmes still had major problems in assembling and erecting the bridge, as the plans provided to him by George Darbyshire, did not correspond with the bridge as shipped. In giving evidence to the 1860 Parliamentary Select Committee upon the *"Railway Department,"* Holmes describes the problems: *"The plans were grossly inaccurate", "so bad that Mr. Darbyshire was going to send home to England for an overseer from the Messrs. Farbairn to oversee the bridge; it came to a standstill." "drawings … were so different from plates, we had to throw them aside." "had to cut the plates and have castings, there was nearly £4,000 extra."*

Holmes had to put up the bridge without accurate plans, and there were many delays due to acknowledged problems with plans from Darbyshire's office.

"The rivet holes not coming one over the other; a practical man - a practical engineer, like Messrs. Fairbairn, had to make those deviations from the office plan that were absolutely necessary for the permanency of the work, and those alterations were not known by Mr. Darbyshire or his assistants, and they were so various and so numerous that the contractor was in a very curious mess; in fact, we had to work them out by our own experience; we had to track Messrs. Fairbairn's idea."

The first government railway from Melbourne to Williamstown (and connecting to Geelong) was finally completed and opened, as well as the line to Sunbury, on 13 January 1859. [147]

In 1912, to enable heavier railway traffic loads, Mephan Ferguson was contracted to replace the box girder span with a through hog-back Pratt steel truss structure, raised a few feet above the previous bridge level. The work was successfully undertaken without disrupting railway traffic and was completed in 1914. [148]

Today the 1914 steel truss railway bridge still stands on the 1858 bluestone abutments of the Saltwater Railway Bridge, and is still in constant use. It is of state significance and is included on the Victorian Heritage Register. [149]

The 90 ft span Stoney Creek Bridge was originally designed to cross over a future canal on Stoney Creek, but that never eventuated. Today, the bluestone abutments survive but have been altered and the superstructure has been replaced with shorter concrete spans over a central pier.

Today the Cole Street Railway Bridge at Williamstown, with its bluestone abutments and wrought iron plate girders, strengthened 1916, is still in use and is listed within the Hobson's Bay Heritage Study and Planning Heritage Overlay. [150]

George Holmes and Co. were awarded many other contracts on the main trunk railway lines, including the rail-over-road bridge at Dudley Street, West Melbourne. [151] At the same time, George was promoting the development of other projects, including the *"Melbourne, Essendon and Kilmore Railway Company"*.

10. Melbourne and Essendon Railway 1859

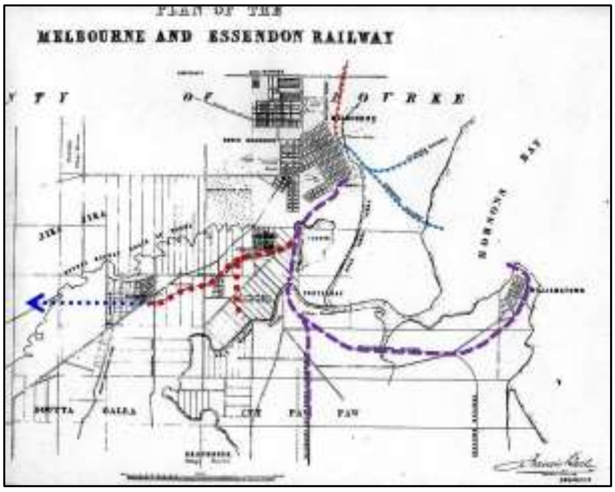

Figure 6: Melbourne and Essendon Railway, July 1859. Francis Bell, Engineer. George Holmes and Co., contractors. [152]

In November 1858, in the prospectus for the £50,000 *Melbourne, Essendon and Kilmore Railway Company*, George Holmes is listed as a Director, with Francis Bell C.E. as the engineer. [153] (Figure 6) The initial proposal was to build a 3.5 mile suburban track from the Government railway at North Melbourne to Essendon, then extend it to Broadmeadows, Kilmore, and beyond. Given that the Victorian government had the 'mandate' for country railways, this was a brave move, and not without its opponents.

Furthermore, unlike other Suburban Railway Companies, it was *"intended to use the Central Railway Depot, at the end of Collins-street, as a terminus, and to traverse the Murray River Railway across the swamp to a point adjoining Mr. Smith's brickworks, from whence the line will proceed directly for the new Cattle-yards and Essendon"*, and hence required leasing Victorian Railways lines and the terminus.

The company's bill was approved by Parliament [154] and George Holmes and Co. were awarded the contract to construct the railway.

On 23 July 1859, the Governor of Victoria, Henry Barkly (1815–1898), [155] performed the ceremony, for 'cutting the first turf'. He was escorted by the Victoria Mounted Artillery Corps, and that probably included Edward Richardson in uniform. Richardson had been promoted from Sergeant to Lieutenant on 7 Dec 1857, [156] and was later promoted to Captain on 30 May 1861. [157]

After many speeches and toasts all around:

"Mr. Holmes, in returning thanks, said that he felt proud to see so many of the citizens of Melbourne present on that occasion. He thought that if the Exploration Committee did not look out, the Melbourne and Essendon Railway Company would land their passengers at the Gulf of Carpentaria before the exploring party left Melbourne. (Laughter.)" [158]

And after indulging in refreshments and a cold collation at the "New Inn", the Governor mentioned that *"it is the intention of the company to make it the direct northern line to the Murray and to Sydney.."*

This was not the type of message you would really want broadcast, especially when you needed to build a co-operative arrangement with the Victorian Railways to lease their carriages, and run your trains on their tracks.

The line was completed in 18 months, and trains were operated to Essendon for the official opening on 22 Oct 1860, [159] again with speeches, toasts and a luncheon for 60 guests at George Holmes Moonee Ponds house *'Le Beau Sejour',* the guests having walked from the Moonee Ponds station along a road, later named Holmes Road. [160] Regular railway services commenced from 1 Nov 1860. There were five intermediate stations on the line, Kensington, Newmarket, Ascot Vale, and Moonee Ponds.

On 28 February 1861, a short branch line was opened from Newmarket to Flemington Racecourse, in time for the running of the first Melbourne Cup in November of that year. Robert Cooper Bagot (1828-1881) [161] another local civil engineer, was the main driving force in establishing, designing and developing the racecourse and the branch line. By now, Holmes was a major share-holder in the Railway company, and was probably benefitting from the land boom that followed the opening of the railway. [162]

Also in February 1861, George Holmes and Co. were awarded the contract, by the St Kilda and Brighton Railway Company, to extend the railway from North Brighton (Bay Street) to Brighton Beach for £25,000. [163] [164] The work also included the construction of the Brighton pier, and the short pedestrian tunnel between the end of the Brighton Beach station and pier. The completed railway line to Brighton Pier was opened on 20 December 1861, with a special train from Melbourne, followed by a lunch at the Royal Hotel. After many toasts all round, …

"Mr. Holmes, in returning thanks, said that at one time he had intended to go to the Gulf of Carpentaria, but, meeting the bay on every side, he stopped at Brighton, and he considered it a right direction. It was but a little time ago since

Canada had but twelve miles of rail ; it was now a perfect network of railways; and he hoped strongly to see the mere 2,000 miles between this and Carpentaria shortly covered in the same manner, (Laughter.)" [165]

By then Holmes and Richardson were ready to move to New Zealand - on 16 April 1861 they had agreed to carry out the contract to build the Christchurch to Lyttelton railway and tunnel, on the proviso that *"the description corresponded with the fact".*

Sadly, on the 28 April 1861, Richardson's wife Margaret died, aged 28 years, [166] [167] and very soon after all his household possessions were sold [168] in preparation for a permanent move to New Zealand.

Like most private railway companies then, the Melbourne - Essendon Railway Company's income barely covered its operating costs, it was unable to service the rising costs of its borrowings, pay dividends, or gain approval to extend the line – and that would probably have been seen as too much of a threat to the Victorian Railway's trunk lines.

The 1860 Parliamentary Select Committee on the *"Railways Department"*, heard evidence from engineers and contractors, many associated with the private suburban Railway Companies, including Holmes. The report was rather damning of the Railways Department and the Engineer-in-Chief, George Christian Darbyshire (1820–1898), and he resigned on 5 May 1860. [169] Thomas Higinbotham, the brother of George Higinbotham, Attorney General, was appointed Engineer-in-Chief. Many of Darbyshire's key engineers left shortly after Higinbotham took office. Higinbotham was unsympathetic to the suburban lines, and he later had many disagreements with other engineers, and appears to have lacked practical detailed applied engineering knowledge and skills.

The Essendon Railway directors by now were committed to negotiating a sale price, but the process dragged on. Without having come to any agreement with the government, the company closed the line on 1 July 1864.

The line was finally purchased by the government for £22,500 in August 1867, at that stage it was in a serious state of disrepair beyond Newmarket. The Flemington Racecourse line was re-opened in time for the 1867 Melbourne Cup and after 7 years, in 1871, the line was finally re-opened to Essendon.

The 'North East line' was quickly extended in sections beyond Essendon in 1872–73. The line was open as far as Wodonga on 21 November 1873, linking at Albury with the main railway line to Sydney. And these days, linking to Brisbane and beyond towards the Gulf of Carpentaria.

The other three private suburban railway companies in Melbourne merged in 1865 to become the Melbourne and Hobsons Bay United Railway Company, and they too were eventually purchased and became part of Victorian Railways in 1878.

11. Holmes and Richardson in New Zealand

Little needs to be said here about the construction of the Lyttelton to Christchurch Railway. There are many excellent contemporary papers describing the construction including those of Dobson, the engineer for the Province of Canterbury, and the engineer for the railway. [170] [171] [172] However a few key points are worth repeating.

The tunnel was one of the most significant engineering achievements in New Zealand. It was the first rail tunnel in New Zealand, and for many years the longest tunnel. It was the first tunnel in the world through the wall of an extinct volcano and provided a unique insight into the geology of a volcano. This also posed unique engineering problems dealing with the changing strata. The syphon for drainage of the upper half of the tunnel was the longest in the world, and the ventilation system was so successful that it was used in constructing the Mont Cenis tunnel from Italy to France.

The agreement to construct the Lyttelton and Christchurch Railway over a period of five years from 1 June 1861, for a sum of £240,500, including the 2,838 yards long tunnel and stone portals for £195,000 was signed on 1 May 1861. The full text of the contract was reported in the *"Lyttelton Times"*, 22 May 1861. [173]

Construction of the tunnel began in July 1861, and the line was opened in December 1867. The contractor had to manage maintaining the labour force over a period of six years, through two gold rushes, and the difficulties of the work site. In the end, both Holmes and Richardson were paid in land grants by the Provincial Government.

Holmes built the first part of the line between Christchurch and a temporary terminus at the Ferrymead wharf and the line started operating from December 1863. Locomotives and rolling stock were brought in parts over the Sumner bar and assembled in the open. As the line was the 'Irish Gauge' of 5 feet 3 inches, the unused locomotive from the Melbourne to Essendon Railway, that was built by Slaughter Gruning & Co. of Bristol, was acquired and used as an engine for ballasting duties.

George Holmes and Co. were also contractors for other works in the Province, including the railway line south from Christchurch to the Rakaia River, and the Iron Swing Bridge, over the Heathcote River on the Sumner Road This interesting timber bridge with a central iron swing span providing two openings of 31 feet each, was built 1862–1864, for about £5,500. The swing bridge replaced the ferry service, and it could be readily opened for the passage of vessels by a single person.

12. Conclusion

The lives and engineering works in Victoria of our three engineers - Samuel Brees, Edward Richardson, and George Holmes – who first came together to build Brees Bridge, were true engineering pioneers. Tackling tasks that many others would not dare to attempt, and in doing so, have left us richer for their endeavours. This paper has helped fill many gaps, but more research needs to be done before a thorough catalogue of their works can be completed.

Not long after the completion of the railroad to Christchurch, in November 1868, Dobson moved to Melbourne to take up a two year appointment as engineer for the Melbourne suburban railways, and then worked for five years on water supply works in Geelong and Malmsbury, Victoria, before returning to New Zealand in 1876.

Richardson married again and had another family. He became a politician, including terms as the Minister of Public Works for New Zealand. Of the Department's Ministers in the 20 years to 1890, *"only E. Richardson had any technical knowledge – he was a qualified engineer".* [174] Many biographies have been written about him. [175] Some of Richardson's relatives came to New Zealand to assist with construction works, so more research in this field would be worthwhile.

Holmes was associated with many large properties and homes, and purchased *Huntley*, at Riccarton in 1877, where he died on 21 September 1877, aged 55. His only son George died shortly after, so his estate was passed to his brother John Holmes. John was a surveyor and a notable politician in Canada, who later moved to New Zealand. Many of Holmes' nephews and other relatives who had assisted him with managing the tunnel works, also became large property owners in Canterbury.

Today, historic *Huntley* still survives, but the large homes of Holmes and Richardson in Essendon, Victoria have been demolished. Their names live on in the streets in Essendon, Victoria, and in Holmes Park in Riccarton, Christchurch, New Zealand.

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The only complete copy in the colony.
Brees's Glossary Architecture and Engineering, £1 5s.
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AN EXERCISE IN LARGE SCALE JOINERY: RESTORATION OF THREE HISTORIC WELLINGTON & MANAWATU RAILWAY CARRIAGES

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Abstract
Three railway carriages built by the Wellington & Manawatu Railway Company at Thorndon, Wellington, 1904-08 survive, the last complete vehicles of the Company's rolling stock. They are in process of being restored in the Hutt Valley, Wellington, to as near "as-built" condition as possible. These carriages were built using plans based on a batch of earlier carriages built for the Company in Philadelphia, Pa., United States of America. Much of the timber used for their construction was recycled from material salvaged from a large viaduct built of native timbers in 1886.

These carriages are notable in New Zealand because their structural design uses composite wood and steel trusses built into the sidewalls below the window line, and their construction made extensive use of re-cycled kauri timber salvaged from a large viaduct. They are also the last complete rolling stock built by the Wellington & Manawatu Railway Company which was New Zealand's most successful privately built and owned railway. In a number of ways, the Company was in advance of New Zealand's Railways Department practice, this being reflected in the design, construction and fittings of these three carriages.

Volunteer work continues on the project, having begun in earnest in 2004. An adequate workshop had to be built before restoration work began. One carriage is nearing the end of restoration and was first displayed publicly during an open day on 18 October, 2014. A second has been stripped to its framing. Replacement frame timbers are being prefabricated for those members that will have to be replaced because of advanced decay. The third complete surviving carriage has been received on site but is unlikely to be worked on by the present team before the other two are more significantly advanced.

1. Introduction

Figure 1: WMR 48 in the project workshop before restoration began, 2004.

Our project began when the New Zealand Railway & Locomotive Society Board of Management (NZRLS, the Society) received a request from its Hawkes Bay Branch that it assume responsibility for railway carriage No. 48 built by the Wellington & Manawatu Railway Company (WMR, the Company), later New Zealand Railways (NZR) carriage A 1126 (Figure 1). This carriage had been used as clubrooms at Clive, near Napier, from 1960 until it was transferred to Gracefield, Lower Hutt, in November 1994, in an unsuccessful bid to find a sponsor for it to be restored.

The Branch was able to supply a significant sum of grant monies which the Board put towards the cost of a suitable workshop building to house the carriage for its restoration.

When our building was sufficiently complete to protect WMR No. 48 from the weather, it was brought to the site at Silverstream, Hutt Valley, and formally rolled in on 6 March, 1999. Work did not commence immediately, until a permanent floor could be built. When funds permitted, a concrete floor with two railway roads built in was completed and the collection of necessary woodworking machinery began. Three phase electrical supply was connected and the building wired with plenty of fluorescent lights and sockets. Other services, water, sewer, telephone, had to wait until much later, again for funding reasons.

Our first significant grants were received from Stout Trust and from Weta Workshop, for which we were very grateful. They unlocked many subsequent sources.

The project has grown from that point. The other two surviving complete WMR carriages have come to the project through the generosity of various Society members, so that we now have all three complete remaining WMR vehicles.

2. The Wellington & Manawatu Railway Company

This Company was floated in February 1881 with the objective of building a railway to link Wellington with the Manawatu district via Wellington's west coast. The Company's history is recorded in the book *Uncommon Carrier*, by K R Cassells. [1] At that time, the government was unable to fund any significant new railway because of lack of capital. The WMR's formal opening was on 3 November, 1886, when the Governor drove the last spike at Otaihanga, Paraparaumu.

As the Government was still very short of funds, it could not buy the completed line, as envisaged by the Company. Instead, its Directors had a railway they had to run and to make profitable. They did so, paying dividends from 1891 onwards. In financial terms, at least, no other privately owned railway in New Zealand has ever been as successful.

The Directors and Engineers quickly realised that their best operating model was the rapidly expanding railroads of the United States of America (USA). The Company adopted North American practices widely, bringing its practices ahead of NZR's, often by decades. Examples of this include the use of telephones for communications and to control traffic, and the use of electric lighting in carriages and in its Thorndon yard, Wellington. Increasingly, rolling stock was obtained from or modelled on that of North America.

With the expectation that the North Island Main Trunk railway (NIMT) between Wellington and Auckland would be completed in 1908, the Government served notice that it would exercise its right to buy the Company, so that the whole NIMT would be controlled and operated by the NZR. Control of the WMR passed to NZR on 7 December, 1908.

3. WMR Passenger Carriages

The WMR built and operated a total of 53 passenger carriages (one other was converted to a dining car on arrival in New Zealand), plus three dining cars. Forty carriages were built in North America 1885-1902; two at NZR's Addington workshops, Christchurch, in 1886; and another 12 carriages were built in the Company's Thorndon workshops 1904–08.

Three of these last are the carriages included in the project discussed here. All three were built as second class saloon cars, with bench seats arranged in two rows, one along each side wall. Seats were wooden, with leather upholstery padded with horse hair.

4. Carriages included in the Project

4.1. General Description

Figure 2: WMR 36 being built by Jackson & Sharp, Philadelphia, Pa., USA, 1902.

Figure 3: Interior view of 36 as built.

Structural and fittings design in these three followed North American practice, as a batch of similar carriages built in 1902 by Jackson & Sharp of Philadelphia, Pa,, USA (Figures 2, 3). The main load bearing structure is a composite truss built in to each side wall, comprising wooden floor beams and a steel tie anchored at each end of the body. The tie rises diagonally to a cast post over the bogie centres, then runs horizontally under the window sill to above the other bogie centre. The two end arrangements are mirror images of each other.

To ensure the steel tie is kept in tension under load, a steel truss rod under each side wall between the bogies has a left and a right-hand threaded turnbuckle to tighten it. Tightening the truss rods has the effect of lifting the whole body to a hogging camber, making sure the trusses in the walls will work as intended.

This was a more efficient use of materials than was NZR practice of the time. Wood was readily available as a construction material in both North

America and New Zealand, whereas steel was relatively expensive. Consequent on this, and on supply problems, there was an incentive to use steel only where absolutely essential. NZR practice followed British design principles of building a steel underframe that provided all load-bearing structural functions. Wooden framed and sheathed bodies were then built by NZR on top of the steel underframes.

As far as possible the programme under which these WMR carriages were built used native timbers salvaged from the original wooden trestle viaduct across the Belmont Valley, just north of Johnsonville, Wellington. This viaduct was replaced with a steel structure in 1904. Kauri was the main timber used for body-building. The largest members are six floor sills the length of the carriages' bodies, 8" x 5", 44'-4' long (200 mm x 125 mm, 13.5 metres long). The two central sills that take buffing forces are hardwood. The other four sills are kauri.

Internal match-lining of the saloons was kauri up to the window sills, American oak where visible above the seats from the window sills up and across the ceilings. Internal partitions and draught screens were all American oak, panelled. All interior woodwork was varnished.

The floors are double-skinned with longitudinal planking and the spaces in between skins are packed with wood shavings for better insulation.

There are 14 main lifting windows and another 14 clerestory windows along each side of the carriages included in our project. Each end wall has lifting windows flanking the entry doors.

Second class cars like these were painted a red-based colour which appears to have weathered to a light brown in time. We were fortunate to obtain a flake of the original paint for colour matching from under a fitting installed by NZR. Roofs were painted slate grey. Underfloor areas, bogies and brake gear, etc., were black.

A water closet and hand basin were provided in a separate compartment in each car. Four electric chandeliers, fed by batteries carried in some guard's vans, were fitted and there were two kerosene burning lights for use when electricity supply was not available. Available construction plans make no provision for a light in the toilet compartment. No form of heating was provided.

One apparent anachronism was the fitting of dead buffers. These were short sprung buffers located each side of the main, Norwegian pattern buffer-couplings, used in common with NZR. If the main coupling broke, the dead buffers prevented adjacent vehicles from closing up fully on each other. They had been developed for this reason in North America in the days of link and pin couplings before the Master Car Builders' knuckle-pattern coupling was adopted as standard in 1890. With link and pin couplings there was no other means of protecting shunters (switchmen) when making a coupling between moving vehicles. Broken couplings are still a significant hazard when they occur.

Westinghouse automatic air brakes were fitted from new. Their operating principle is that the air pressure holds the brakes off. Reduce the pressure in the train pipe and the brakes are applied proportionate to the train pipe pressure reduction.

4.2. The Project Carriages

The first carriage to come to the project was No. 48, built in 1906. As with all the Company's rolling stock, it was bought by the Government in 1908 and added to NZR's stock.

WMR standard fittings were replaced by NZR standard items over time. For example, the electric and kerosene lights were replaced with Pintsch compressed gas lights. The dead buffers were removed. End platforms railings and gates together with monogrammed glazing in the doors were replaced with standard NZR fittings. Other lesser modifications were made over the years.

No. 48 was bought by the NZRLS Hawkes Bay Branch in 1961 for £25. Removal from NZR tracks to a close by site at Clive railway yard was greatly facilitated by a case of beer given to the local track gang!

From there No. 48 came to Wellington in 1994 and to the NZRLS site at Silverstream in 1999, as discussed above. It was in the best condition of the three carriages as received by our restoration team, as it had been subjected to regular maintenance after it passed out of NZR use. It was protected from the weather when stored at Gracefield through the good offices of the Rail Heritage Trust and New Zealand Rail Ltd.

Second to be received was carriage No. 52 which had been built in 1907. This was bought in 1959 by the NZRLS Wanganui Branch. No. 52 was then sold to the traction engine society in Marton. They removed the bogies and the truss rods when these were damaged during unloading. In 1974 ownership of this carriage was transferred to the NZRLS Wellington Branch which later became the Silver Stream Railway. The carriage was stored at Seaview, Lower Hutt, until it was transported to Silverstream in 1988. The body has sagged over time after the truss rods were removed. As a result of prolonged exposure to the weather, this carriage has deteriorated worst of the three, with much rot in structural members (Figure 4).

Figure 4: WMR No. 52 being transported to the project workshop. The body sags after removal of truss rods and much rot is apparent.

No. 42 (built 1904) was bought by the late Bob Mann and stored for many years sheathed in corrugated iron at the base of the Bush Tramway Club in Pukemiro, Waikato. Bob bequeathed it to NZRLS and it was received on our site 23 April, 2014. This carriage has also deteriorated over the years, being in intermediate condition between that of the other two as received. Its internal layout differed from that of Nos. 48 and 52 by having the toilet at the northern end, above the bogie. The latter two had the toilet in the centre, dividing their interior accommodation into two saloons.

The engineering heritage values of these carriages include that they:

- were built to the best North American practice of their day;
- are distinctive in New Zealand to the WMR, a company that had advanced technical standards and practices for its time;
- exemplify active materials conservation policies of the period before 1908.

Their heritage importance was recognised by the people who saved them in the period around 1960 when they became surplus to NZR operations.

5. Restoration of WMR 48

5.1. Conservation Plan

A formal restoration plan was commissioned from architect and conservator Ian Bowman by the Rail Heritage Trust. [2] We received this in 2002.

Conservation policies in accordance with the International Council on Monuments and Sites (ICOMOS) New Zealand Charter for the Conservation of Places of Cultural Heritage Value were prepared for the guidance of the project team. These covered:

- Long term conservation of No. 48;
- Interpretation of the value of the carriage;
- Its then physical condition;
- Recommendations for repair; and
- Future maintenance.

As far as possible, the principles and polices of his plan are being followed.

The project team decided at the beginning that No. 48 would be restored to its original as-built condition or as near to that as possible. This policy has been extended to the other two carriages.

5.2. Research in Preparation for Restoration

Considerable research was carried out in New Zealand and in the USA to establish as much authentic information on the original condition of the carriage as possible. Relevant plans and photographs were obtained from sources in both countries. Many of the WMR records had been lost or destroyed through the years, but engineering drawings were available from archival sources and from New Zealand Rail Ltd. mechanical engineering records.

Engineering drawings for the Woods safety gates, standard on WMR carriages, were located in and copies obtained from the Illinois Railway Museum Pullman Library, Union, Ill., USA.

Despite a great deal of effort, some details could not be established with certainty. For example, only one photograph has been found showing a WMR carriage kerosene light and no view has been found of the interior of a toilet compartment. Available plans are insufficiently detailed in this area and some details such as doors heights and choices of specific joinery mouldings have involved much discussion with knowledgeable people.

The design of the electric light chandeliers was able to be deduced from a reproduction manufacturers' catalogue of 1905 and from repairs to the ceiling after NZR removed these fittings.

5.3. Restoration 2004–14

Restoration commenced in June 2004. Annual progress was recorded in the Society's annual reports [3], from which this summary has been prepared.

No. 48 was in the Society's workshop, protected from the weather. The building had been completed with two parallel rail sidings set into a reinforced concrete floor. Three-phase electric power supply had been connected and a comprehensive collection of woodworking machinery was being obtained from a number of donors.

Sufficient toughened glass for the windows for carriages Nos. 48 and 52 had been donated in 2003. Our general policy has been to obtain materials and to make parts for both carriages at the one time. Items for No. 52 are being held ready for when they are needed.

When work began in 2004 benches, kitchen facilities, and beds installed by past owners were removed from No. 48. One exterior wall was stripped of its tongue and groove (t & g) timber cladding so the condition of the framing could be assessed. All remaining non-original fittings were removed.

Fund-raising also commenced. We found the most successful approach was to seek multiple modest sums, each for a specific purpose

Through 2004–05 the carriage was lifted off its bogies, which were taken apart, sand blasted and painted. All exterior cladding was stripped off the framing and 14 wall studs that had rot in them were replaced. Replacement t & g kauri cladding was obtained, cut to size, and primer painted ready for use later.

The following year patterns were made for missing parts of the bogies and replacement castings obtained. New springs for the suspension and drawgear were obtained for both carriages. The old roof cladding on No. 48 was removed to allow broken and rotten roof timbers to be replaced. Some large holes cut in the roof by NZR for gas lights ventilation were patched over. Work began on applying new t & g wall cladding. The tedious and difficult work of stripping paint applied by NZR to the interior match-lining began. We had established from observation that this woodwork was varnished originally.

Donated jarrah floor beams from a building reconstruction site were machined by a joiner, who cut four new headstocks for use on Nos. 48 and 52. Enough glass for use in both Nos. 48 and 52's new clerestory toplights was sand-blasted with a pattern matching the original.

In 2008 all exterior cladding was replaced. Much painstaking sanding was carried out to strip paint from the interior match-lining. The making of new window sashes from mahogany for both carriages began.

Other work carried out in 2007-08 included rebuilding the end entry platforms, including the new jarrah headstocks and the fitting of drawgear, steps and handrails. Very weathered timbers at the ends of the roof were replaced. Work began on machining new main window sashes in mahogany.

During the next year wheels, tyres and axles were checked by a mechanical engineer accepted by New Zealand Rail Ltd and remedial work agreed. One set of axle and wheels was rejected as the tyres were considered too thin, so an acceptable replacement wheelset was obtained. As necessary, axle bearing areas were skimmed to remove pitting caused by corrosion when No. 48 was out in the open. The bogies were then reassembled and run under the body again. Air brake equipment was overhauled, refitted, and everything underfloor was painted black.

The decision was made that the match-lining of the ceiling would be taken down to permit the stripping of all traces of NZR paint. This was when we confirmed that the original treatment was varnish. At this time the original WMR electrical wiring was found. It was replaced with modern insulated wires. We were able to re-use the kauri match-lining and 75% of the oak. The new oak was sourced to match the old and the lining was completed. The floor was lifted and re-laid using new kauri planking.

Blinds were also made and will be fitted to the main windows later in the project.

Pattern-making commenced for the many small metal parts needed to replace lost fittings and ones replaced by NZR. Larger castings include those for the Woods safety gates on the end entry platforms, dead buffers, window openers and luggage rack brackets. The last of these patterns are being worked on at present.

A milestone was reached in April 2011, when No. 48 was taken out of the shed for a test run. It was found to ride very comfortably at low speed on somewhat rough track. Leaks in the air brake piping were marked for later attention.

Through 2011–12 toilet compartment partitions and draught screens adjacent to the internal doors were made and fitted. Varnishing of all exposed interior woodwork was begun. Windows are complete except for their metal fittings and final painting.

In 2014 interior woodwork is complete except for all doors, which are yet to be made. Top coat painting of the exterior was completed this spring. Work is beginning on making replacement electric and kerosene light fittings.

5.4. Remaining Work to Complete No. 48

Castings are needed for a multitude of small fittings, for the Woods gates, and for the dead buffers. Doors have to be made. The main windows sashes are ready for final painting and fitting. Once the Woods gates and dead buffers are made and fitted the end platforms can be painted.

Replacement electric and kerosene lights have yet to be made.

A final step will be contracting a sign-writer to apply linings, company name, carriage number, and class designation on each side of the carriage.

6. Restoration of WMR 52

No. 52 was donated to the Society in 2003. It had been left exposed to the weather for a long time and was in very poor condition, exacerbated by the removal of the truss rods earlier. The carriage was jacked off its bogies and placed on levelled trestles in the workshop to stabilise and dry out.

In 2012 a separate restoration team stripped the cladding, match-lining and floors. None of this timber was salvageable. The four kauri floor sills had advanced rot in their mid-sections and also need to be replaced.

Timber was bought in 2014 which allowed a start to be made on prefabricating replacement wall studs and diagonal braces that need renewal. Laminated finger-jointed macrocarpa beams have been obtained to replace the rotten kauri floor sills.

7. The Future of the Project

While there is no specific target date to complete restoration of No. 48, this should be achieved within the next two years.

Work has begun on the structural repairs needed for the restoration of No. 52. We expect this project to continue in a manner similar to No. 48.

At this stage there is no firm proposal to commence work on No. 42.

Once the project is complete, we will have three second class WMR carriages restored to as near original condition as possible. Our intention is that they be held under cover and on display, available for use on special occasions. KiwiRail has indicated that permission could be given to place them on its tracks for special events. However, this will be subject to stringent safety conditions and precautions, such as yard movements only, or under block of line conditions to keep them clear of modern trains.

A beguiling thought is that some members of our kindred society, Steam Incorporated, of Paekakariki, have the salvaged frames from the engine and tender of WMR locomotive No.9. They have begun a long term project for the restoration of this with the objective of producing a working locomotive again. Perhaps one day, No. 9 and our carriages could come together to recreate a genuine WMR train?

8. Conclusion

The Society's management committee was aware it was taking responsibility for a significant project when it agreed to accept WMR No. 48 from our Hawkes Bay Branch. The project has grown with the addition of the other two carriages but is proving to be within the resources of the Society and its restoration team as long as time is not a constraint.

The carriages are distinctive and technically notable within New Zealand. Through their original owners they provide a link with Wellington's founding retailers and commercial entrepreneurship of 134 years ago.

9. Acknowledgements

I am grateful for the help given by Messrs C E P Davis (project manager) and W W Prebble as I prepared this paper. They are leading this ambitious project and have done most of the research that has made our project possible.

Many people within NZRLS have contributed in a wide range of ways to this project. Without their work these three historic WMR carriages would have been destroyed long ago.

We are very grateful to a wide range of funders whose grants have made possible progress at a rate well in advance of what NZRLS could achieve from its own resources.

Photographs were taken by or obtained from W W Prebble (Figures 1 and 4) and the Delaware State Archives (Figures 2 and 3).

10. References

[1] Cassells, K R, *Uncommon Carrier, the History of the Wellington and Manawatu Railway Company, 1882-1908,* Wellington, NZ, NZRLS, 1994.

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IMPROVING THE RISK MANAGEMENT OF NEW ZEALAND'S HISTORIC HERITAGE AND THE ROLE OF THE HERITAGE ENGINEERING COMMUNITY

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Abstract
This paper provides of an overview of the risks to New Zealand's built historic heritage, including natural hazards. It analyses reasons for the demolition of heritage buildings and structures, including engineering heritage, that were formerly entered on the New Zealand Heritage List/Rārangi Kōrero. The paper examines the current framework for managing risks to historic heritage, and investigates issues and gaps. It suggests emerging opportunities for collaboration and input needed from the heritage engineering community.

1. Introduction

Historic heritage is a finite, non-renewable resource, and it is recognised as being a matter of national importance under Section 6 of the Resource Management Act 1991. Heritage contributes to our sense of place, national identity, and community. Heritage places and areas are popular tourist destinations.

The Canterbury earthquakes in 2010 and 2011 resulted in a devastating loss of historic heritage. The destructive force of the quakes focussed attention on the fragility of our built environment and the risks posed to and by heritage buildings, particularly unreinforced masonry buildings. Insurance became difficult to get for buildings seen as being at risk. Councils focussed more effort on assessing the earthquake-prone status of their building stock and heritage building owners became aware that they may need to upgrade their buildings to meet the current building code. Legislative amendments to the Building Act 2004 have been proposed to make this mandatory within set timeframes for all non-residential buildings.

Severe earthquakes are an infrequent, unpredictable, and potentially catastrophic threat to heritage buildings. However other natural hazards occur much more frequently, with effects that may be less severe and more localised but are potentially cumulative.

This paper looks at the threats to the long term survival of New Zealand's historic heritage. It examines records of demolition of identified historic heritage and the reasons for demolition. It evaluates the ability of current legislation to protect historic heritage from hazards, including gaps in the legislation, and proposes opportunities for agencies and professionals to work together to address these gaps.

2. New Zealand is a dynamic landscape

New Zealand's location in the southern ocean and linear topography with high mountain ranges means that our climate is subject to extreme weather events such as cyclones, flooding, storm surges, high winds and even tornadoes. Some of these natural hazards have been exacerbated by human development. Many of our coastal areas are at risk from erosion and rising sea levels. Climate extremes mean that forest fires are a risk in some areas in summer, whereas heavy rain and snowfalls affect other areas in winter. Earthquakes are common, and tsunami, although rare, can occur.

3. Natural hazards that pose a risk to historic heritage

Risk is the "effect of uncertainty on objectives" and is often expressed as a combination of the consequences of an event and the associated likelihood of that event occurring.[1] Figure 1 shows New Zealand's risk profile, expressed as estimated frequency of occurrence of an event type and associated consequences. The events in the lower right quadrant of the diagram are catastrophic events which may occur very infrequently, whereas the events at the top left of the quadrant are events that may occur frequently but where the effects are minor. The events most likely to affect historic heritage are floods and severe weather (bright blue) and earthquakes and volcanic activity (mustard).

Since 1967 there have been 167 declarations of states of emergency involving natural hazards earthquakes, landslides, tsunami, floods, severe weather, and wildfire, as shown in Table 1.

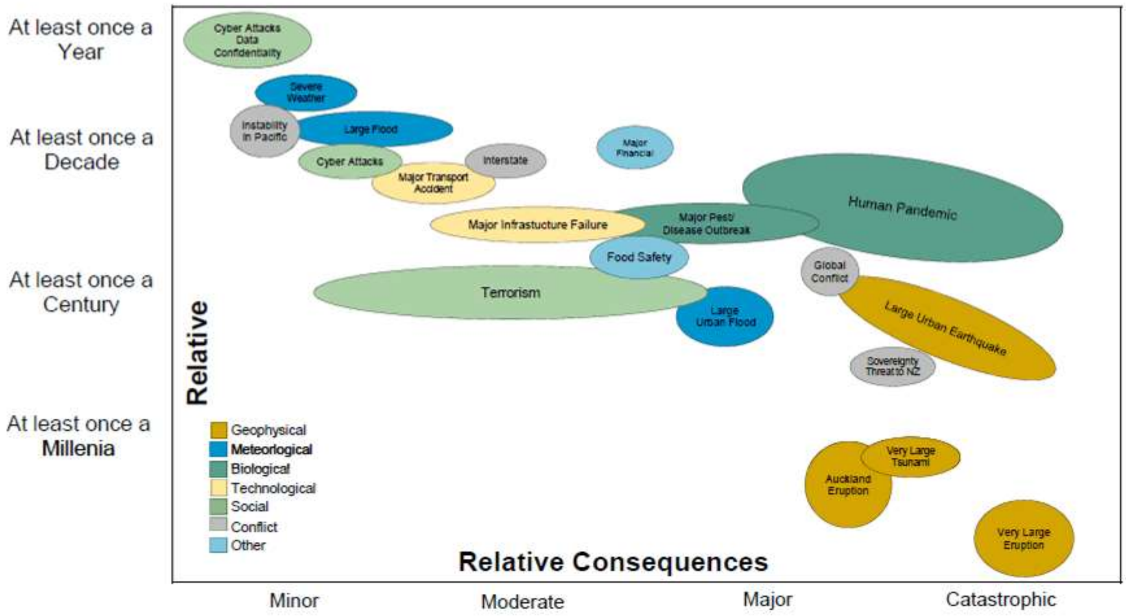

Figure 1: Relative frequency of occurrence of hazardous events and the relative consequences. Source New Zealand Treasury; *2014 Investment Statement: Managing the Crown's Balance Sheet.* [2]

Table 1: Breakdown of types of civil defence emergency: Ministry of Civil Defence "Historical Emergencies" http://www.civildefence.govt.nz/resources/historical-emergencies/) [3]

Type of emergency	Number since 1967
Floods	122
Severe weather	17
Earthquake	9
Wildfire	7
Landslides	6
Tsunami	4
Volcanic unrest	1
Other	1
Total	167

The states of emergency were declared primarily because the extreme events could affect people, economic activity, settlements or key infrastructure. Localised events, such as severe weather, could pose a threat to historic heritage but not meet the criteria for declaring a state of emergency. For example, BRANZ estimates that natural hazards result in the following damage to residential properties each year:

- 1086 homes are damaged by flooding
- 280 homes in New Zealand suffer wind or storm damage
- 76 homes are damaged by coastal erosion.[4]

Climate change research suggests that the frequency of severe weather events could increase, with more storms, flooding and high winds and in some areas increased risk of drought and forest fires. Heavier rainfall can also lead to unstable building foundations and landslides undermining or damaging buildings.[5] Warmer climates may allow pests that attack building fabric, such as termites, to spread and thrive.[6]

4. Human activities that pose a risk to historic heritage

Development is a major threat to historic heritage. Modernisation of cities (the construction of new buildings, roads, and infrastructure) has resulted in the loss or compromise of heritage urban fabric. Often, heritage is simply "in the way", and heritage buildings may need to be upgraded or retrofitted to be commercially viable.

Fire, usually starting within a building or deliberately lit by vandals, poses a particular localised risk to heritage structures. Vacant heritage buildings are also at risk from deterioration through lack of maintenance, and vandalism.

Whereas the frequency and severity of calamitous natural events cannot be controlled, the threat to heritage posed by human activities is more amenable to risk reduction through controlling the activity.

5. New Zealand's heritage is vulnerable

Since the Canterbury earthquakes in 2010–2011, New Zealanders have become acutely aware of the risk to heritage buildings posed by natural hazards. The media often report on the loss of heritage buildings and structures, demolition precipitated by earthquake damage, fire, extreme weather, vandalism, delayed maintenance or economic imperatives. Is this a fair representation of the actual loss of heritage?

To answer this question, we interrogated the records of demolitions of heritage structures recorded on the New Zealand Heritage List Rārangi Kōrero (the List) for the last 15 years. This analysis only includes heritage items entered on the List, which may not include all of New Zealand's significant heritage. Other important heritage of local and regional significance is identified on district and regional plans and on other schedules, such as the IPENZ Engineering Heritage Register and Rail Heritage Trust Register.[7]

5.1 What types of heritage we are losing and why?

Significant historic places are entered on the List and classified as Category 1 or Category 2 depending on the level of significance. The List also identifies historic areas (which contain several historic places), wāhi tapu and wāhi tapu areas and, in the future, will include wāhi tūpuna and National Historic Landmarks/Ngā Manawhenua o Aotearoa me ōna Kōrero Tūturu. The List identifies 5709 heritage places and areas, and a breakdown of these into categories is shown in Table 2.

Table 2: Heritage entered on the New Zealand Heritage List/Rārangi Kōrero as at 20 October 2014 (Source: Heritage New Zealand internal database Pātaka)

List Entry Category	Number of Entries
Historic Area	121
Historic Place Category 1	997
Historic Place Category 2	4431
Wahi Tapu	101
Wahi Tapu Area	59
Total	**5709**

The first question to be examined is what type of heritage are we losing? Category 1 historic places are identified as "places of special or outstanding historical or cultural heritage significance or value".[8] Approximately 18 per cent of the historic places (i.e. of Category 1 and Category 2 places) on the List are Category 1. We are losing around six times as many Category 2 buildings to demolition as Category 1 buildings, which reflects the greater number of Category 2 buildings on the List. The number of demolitions by type of List entry is shown in Figure 2. The focus of the analysis is on buildings and structures entered on the List. No wāhi tapu or wāhi tapu areas are identified as having been demolished within the study period. The study does not look at the potential destruction of archaeological sites which are recorded thorough the granting of an archaeological authority.

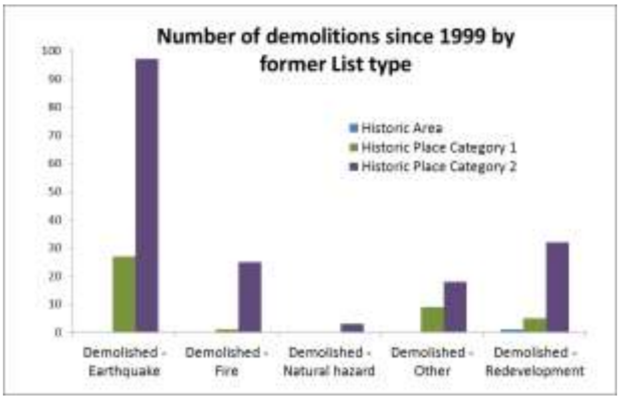

Figure 2: Demolitions of historic heritage by type of event and heritage significance (Source: Heritage New Zealand internal information database Pātaka)

Table 3 shows the proportion of Category 1 historic places demolished as a percentage of total places demolished.

Table 3: Proportion of Category 1 historic places demolished. (Source: Heritage New Zealand internal database Pātaka)

Demolition type	Total Cat 1 & 2	Cat 1	Cat 1 as % of total Cat 1 & 2
Demolished - Earthquake	124	27	22%
Demolished - Fire	26	1	4%
Demolished - Natural hazard other than earthquake	3	0	0%
Demolished - Other	27	9	33%
Demolished - Redevelopment	37	5	14%
Total Demolished	217	42	16%
Total on NZ Heritage List	5428	997	18%

Overall, the percentage of Category 1 places demolished, and in particular those demolished as a result of development or earthquake damage, roughly reflects the proportion of Category 1 places on the List. The proportion of Category 1 places destroyed by fire is very low, but the proportion demolished for other reasons (often neglect) is nearly twice the proportion on the List. Further investigation would be needed to determine the reason for this. Overall, it does not appear that we are losing a disproportionate number of nationally significant Category 1 places.

5.1.1 Examples of historic heritage lost to fire

The Canterbury Roller Flour Mill building in Ashburton was demolished in 2011 after being damaged by fire. This type of building is unlikely to have had any form of fire protection.

Figure 3: Canterbury Roller Flour Mill Original Building, and Concrete Store, Ashburton, (HNZPT).
Originally entered in the List as Category 2 historic places the Flour Mill was lost to fire in 2011.

5.1.2 What type of heritage structures are we losing?

The next question we examined is what types of buildings and structures are lost to demolition. A breakdown by use of the building or structure is shown in Figure 4.

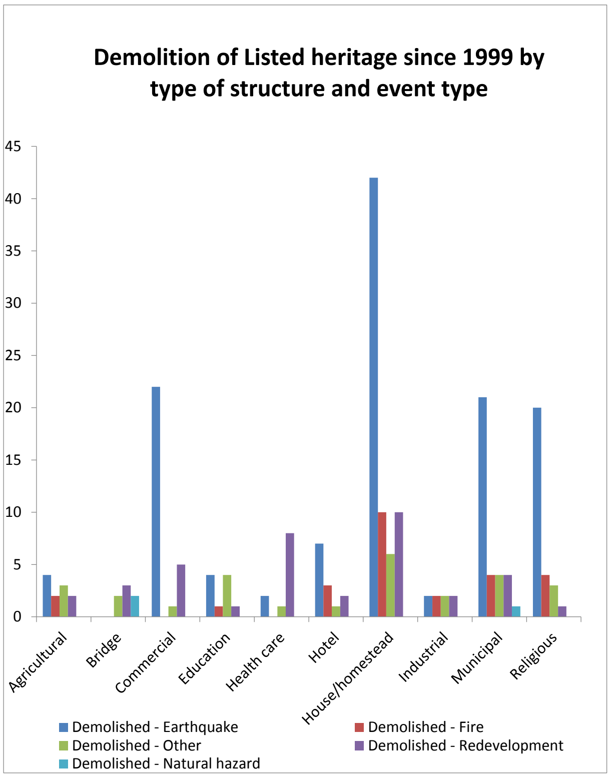

Figure 4: Demolitions of heritage structures by type of building and event type (Source: Heritage New Zealand internal information database Pātaka)

Loss of historic heritage structures is dominated by demolitions after the 2010–11 Canterbury earthquakes. Around one third of the buildings demolished were residential and two thirds non-residential, mainly religious, commercial and industrial buildings. The next most frequent cause of loss of heritage buildings is fire, and again a little over a third of buildings demolished were residential buildings. As seen above, all but one of the buildings lost to fire were Category 2 buildings.

5.1.3 Examples of bridges lost to flood or redevelopment

Several heritage bridges have been lost recently as a result of flood damage, but the number is surprisingly small given that flooding is the most frequent reason for civil defence emergencies and results in significant damage to residential properties. Redundant bridges, replaced by modern structures or no longer required because of rail closures, are also at risk of demolition. An example of a demolished bridge is shown below. No heritage buildings are listed as being demolished due to flood damage, but it is likely that some will have suffered repairable damage.

Figure 5: Mangaotuku Truss Bridge, Stratford (Chris Cochran). Originally entered in the List as a Category 2 historic place. This bridge was built around 1905 and was destroyed in a flood on 15 February 2011.

5.2 Canterbury Earthquakes

As Figures 2 and 4 show, a single catastrophic event can have disastrous consequences for heritage at a regional level. As of October 2014 at least 125 heritage buildings previously entered on the List either as Category 1 or Category 2 have been lost as a direct consequence of the Canterbury earthquakes. These losses were concentrated in Christchurch City, as shown in Figure 6.

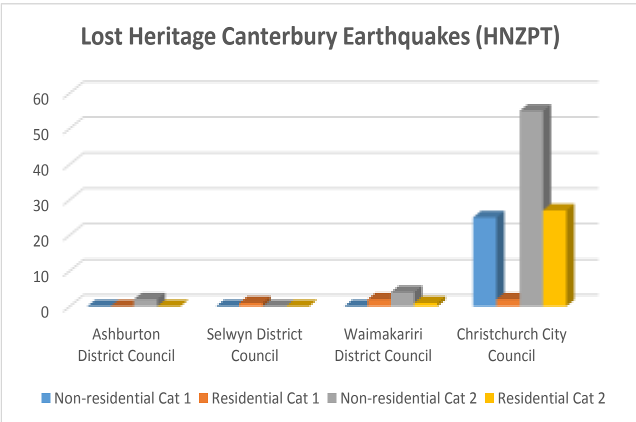

Figure 6: Loss of residential and non-residential historic heritage as a result of damage in the Canterbury earthquakes, by local authority. Source Heritage New Zealand "Lost Heritage" http://www.heritage.org.nz/the-list/lost-heritage/canterbury-earthquakes.[9]

5.3 Has the loss of heritage buildings changed over time?

As shown above, more than half the demolitions within the 15-year study period were due to the Canterbury earthquakes and occurred in the 2011 and 2012 years. To examine demolitions caused by less extreme events, earthquake-related demolitions were excluded from the analysis of changes over this period.

Figure 7 shows demolitions for reasons other than earthquake damage. Redevelopment is the second most common reason for demolition, although decisions to demolish and redevelop a site are usually based on complex factors including the condition of the building, the value of the land, and the costs to strengthen or adapt the building for economic use. Overall, there appears to be a slight downward trend in demolitions per year. Further work would be needed to determine if this is due to a greater value being placed on heritage buildings or whether it is related to economic factors.

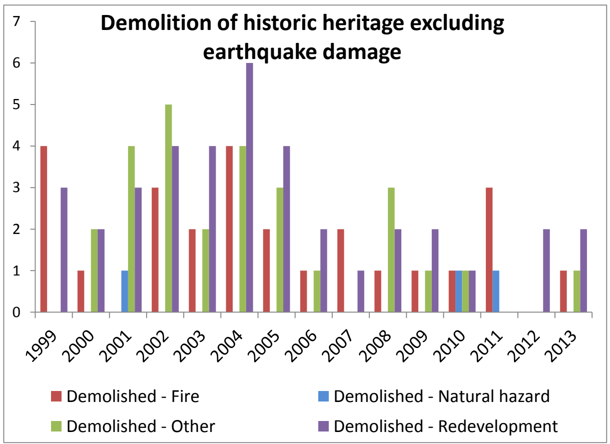

Figure 7: Demolition of heritage by year, excluding earthquakes (Source: Heritage New Zealand internal information database Pātaka)

5.4 Assessment of heritage lost

Based on the analysis of demolitions of historic heritage structures over the last 15 years of historic places previously entered on the List:

- A single catastrophic event can have devastating results for historic heritage – earthquake damage accounted for more than half the demolitions of buildings on the List in the last 15 year
- Development pressure is the next biggest threat to historic heritage buildings and around six times as many Category 2 buildings are lost to development as Category 1 buildings, roughly reflecting the proportions of these buildings on the List.
- Fire is the next biggest threat, and in the last 15 years has mainly affected Category 2 buildings.
- A surprisingly small number of demolitions have occurred as a result of other natural hazards, and these are mainly due to floods damaging bridges. However, this analysis does not take account of the destruction of historic heritage that is not entered on the List, for example heritage that is scheduled in district plans only, or repairable damage.
- The focus of the analysis is on buildings and structures entered on the List. The absence of archaeological sites from this analysis does not mean they are not at risk.

6. Are we doing enough to reduce the risk to historic heritage?

6.1 Assessing risks to heritage

Risk is a function of the likelihood of an event occurring and the consequences of that event, as discussed above and portrayed in Figure 1. The risks posed to historic heritage from natural hazards can be viewed as the intersection of the hazard (likelihood, severity), the exposure of the structure to the hazard (likelihood) and the vulnerability of the structure (consequence), to determine the risk from a particular type of event. This is shown in Figure 8.

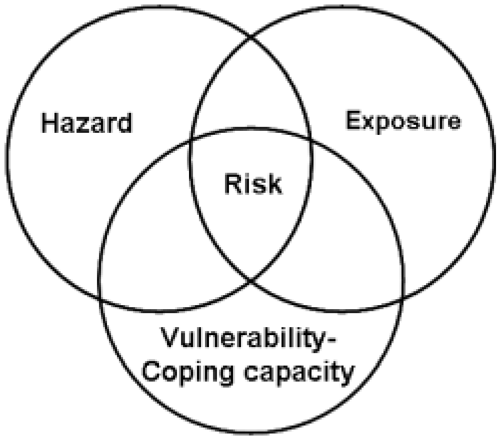

Figure 8: Assessment of risk (Source: Reese and Schmidt 2008 [10])

Cost is a significant factor in decisions on the extent of managing heritage risks. However preventative measures can reduce the long-term financial risk. One international guide on managing disaster risks for heritage states that "Disasters can have great financial consequences: it is much more cost-effective to invest in preventive risk management planning before disaster has struck than to spend large amounts in post-disaster recovery and rehabilitation".[11]

International best practice for managing cultural heritage is based on a number of key principles:

- When planning for disasters it is necessary to consider all risk to all heritage (tangible and intangible) and the potential for multiple disasters (e.g. earthquakes followed by fires, cyclones followed by flooding and landslides).
- Consider where a risk may come from (i.e. both from within the site and external,) and prepare for not only reducing risk, but also response and long term recovery.
- It is important to also consider the role of traditional knowledge in preparing for and responding to disaster (for example oral traditions and histories of previous events).

- In all situations life-safety is of paramount importance.
- Disaster risk management for cultural heritage should recognise the need to reconcile conflicts and engage multiple stakeholders.
- Disaster risk management should be integral to the management of the site and linked to local/ regional and national disaster management plans. Cultural heritage should be mainstreamed into disaster management plans. [12]

Managing risk to heritage structures requires the preparation of a risk management plan, as shown in Figure 9. The process includes setting objectives, identifying and assessing risks, examining measures for prevention and mitigation, planning for emergencies and recovery. The process includes ongoing monitoring and review.

Figure 9: Steps in the risk management process (From Managing Disaster Risks for World Heritage, UNESCO, 2010.[13])

6.2 How do we currently manage these risks?

As discussed above, the hazards posed by environmental factors such as extreme weather and seismic or geothermal events cannot be controlled. Managing exposure to hazards is also difficult, because historic heritage items are at fixed locations and relocation can significantly reduce heritage values.

Other natural hazards such as storms and floods occur more frequently and the probability of an event of a particular magnitude occurring within a specified timeframe at a location can be estimated based on long term records of similar events. Some engineering solutions such as catchment management can reduce exposure of structures to the effects of extreme weather for example, but schemes are not usually designed with heritage protection as a prime objective. One notable exception is the work at Kerikeri where a significant amount of investment by central and local government has gone into reducing the flooding risk to some of our most important historic places.[14]

One of the most important (but often neglected) ways of improving the resilience of heritage structures is regular maintenance. Without good maintenance structures can gradually weaken, thus increasing their vulnerability to catastrophic events. Some heritage structures were not built with the intention that they would stand permanently. Often a poorly maintained structure can degrade to the point that the cost to remediate any damage is greater than the commercial value of the building. In such situations it is more than likely the structure will be demolished and replaced.

Fire protection is critical for wooden structures. As shown in Figure 4, few Category 1 heritage buildings have been demolished as a result of fire in the last 15 years. This may be a result of Heritage New Zealand, in partnership with the New Zealand Fire Service, working with building owners, providing advice and targeted incentive funding. As a result one reason Category 1 buildings seem to be less vulnerable to fire could be improvements to wiring and installation of alarms and sprinklers. Category 1 buildings may also be more likely to be economic to repair after a fire than Category 2 buildings.

Overall, the most effective way of protecting heritage buildings from natural hazards is likely to be to improve the resilience by reducing the vulnerability.

7. Mechanisms for protecting historic heritage

7.1 How well does current legislation protect heritage buildings and structures?

Regulation is one of a suite of complementary tools for improving the resilience of our stock of heritage buildings. This section looks at the regulatory means available to ensure that heritage buildings are maintained and enhanced.

There are three key pieces of legislation that serve to identify, manage and protect historic structures:

- Heritage New Zealand Pouhere Taonga Act 2014 (HNZPTA)
- Resource Management Act 1991 (RMA)
- Building Act 2004 (the Building Act)

In addition, the Conservation Act 1987 assigns the Department of Conservation (DoC) a stewardship role for the conservation of natural and historic resources on land it manages for the Crown. The main way that DoC gives effect to this is by managing and conserving a range of historic heritage sites and providing interpretive information on these sites.

A further piece of legislation, the Civil Defence and Emergency Management Act 2002 (CDEM), manages our response to natural disasters. However, it does not specifically provide for the protection of heritage buildings. We will explore the potential of this legislation and associated planning documents to reduce risks to heritage structures later in the paper.

Both the HNZPTA and the RMA focus on the identification of historic heritage and protection from human activities, as shown in Table 4. The Building Act focuses on setting and enforcing performance standards for new and existing buildings.

Table 4: Legislation related to the identification and protection of historic heritage

	Identify heritage	Protect from inappropriate development	Increase resilience of structure
HNZPTA	Yes	Yes (archaeology) Limited (structures)	Yes (Landmarks) Limited (other heritage)
RMA	Yes	Yes	Limited
Building Act	No	Limited	Yes

The HNZPTA has four mechanisms for identification and protection:

- historic heritage is identified and recognised through entry onto the List
- places with outstanding national heritage value are identified and recognised through entry on the National Historic Landmarks List. A risk management plan must be produced for every Landmark
- covenants, which are an agreement between Heritage New Zealand and the property owner for the purpose of protecting and conserving a heritage item
- Archaeological sites are protected and an authority is required for their modification or destruction. A simplified and streamlined process has been set up to quickly consider work that affects archaeological sites under the Canterbury Earthquake Response and Recovery Act 2011.

The RMA provides for:

- recognition of historic heritage as a matter of national importance, to be protected from inappropriate subdivision, use and development
- recognition of entries on the List when preparing regional policy statements and regional and district plans
- scheduling of historic heritage in district and regional plans, and protection through a structure of rules governing activities that can be carried out
- heritage orders, which are requirements set out in district plans providing for the protection of specific heritage items.

The provisions of the Building Act include:

- requirements for building safety and fitness for purpose, including structural stability and fire protection
- the need to facilitate the preservation of buildings of significant cultural, historical or heritage value.
- a requirement that every territorial authority adopt a policy on dangerous, earthquake-prone, and insanitary buildings including how the policy will apply to heritage buildings
- provisions to manage dangerous, earthquake-prone and insanitary buildings, and dangerous dams
- requirement for territorial authorities to notify an application for a building consent or project memorandum that affects any place (historic place, historic area, wahi tapu, wahi tapu area, or wahi tupuna) that has been entered on the List.

7.2 How do the three key pieces of legislation work together?

Places with heritage values are recognised by entry onto the List and protected through scheduling in district and regional plans and protection from inappropriate activities through rules. However, the ability of the HNZPTA and the RMA to directly require building owners to take steps to reduce the vulnerability of their buildings to natural hazards is limited, apart from requirement to prepare a risk management plan for National Historic Landmarks. No Landmarks have been proposed yet, as the legislation establishing the Landmarks is relatively recent and the policy is currently under development.

The Building Act is the key mechanism for ensuring that buildings are maintained and upgraded to meet current performance standards. Tension can arise between Building Act requirements for buildings to meet these performance standards and RMA requirements for resource consent to undertake major work or demolish heritage buildings. If standards cannot be met, demolition is the likely outcome. Councils can order demolition of buildings on the grounds of risk to public safety, even for a localised issue where a civil defence emergency has not been declared. The demolition of the Category 1 Aurora Hotel in Auckland is an example of council ordering an emergency demolition of a heritage building on the grounds of danger to public safety.[15]

In 2013 the Ministry for Culture and Heritage commissioned a report to understand the role the RMA plays on influencing seismic strengthening of heritage buildings. Seventeen operative/proposed district plans were assessed representing a range of territorial authorities. Only one of the plans in the sample provided an explicit linkage between the RMA and the Building Act, and few gave clear guidance on how earthquake strengthening proposals would be assessed. None of the plans contained provisions addressing the reduction in the vulnerability of heritage structures to other natural hazards.[16]

7.3 Do the protection mechanisms match the risks to heritage?

As discussed above, earthquakes and other natural hazards cannot generally be mitigated, but the vulnerability of structures to these hazards can be enhanced. Until recently the only way to ensure that owners enhance the resilience of heritage buildings was through the Building Act. Where a building consent is required for building work or a change of use, conditions will require that the building meet current performance standards for fire protection and earthquake strengthening.

The earthquake-prone buildings provisions of the Building Act are currently being reviewed to require councils to assess buildings and for earthquake-prone buildings to be rectified within set timeframes. The review identified “too much variability” in council policies as an issue, with some councils not actively addressing the problem and others giving building owners long timeframes to address problems.[17]

8. Dealing with the effects of natural disasters on heritage

8.1 Civil defence legislation and interface with heritage risk management

The Civil Defence and Emergency Management Act 2002 (CDEMA) addresses the sustainable management of hazards, identifying and managing risk, and preparing for emergencies, including response and recovery. Sustainable management in this context takes into account the social, economic, cultural, and environmental well-being and safety of the public and also to the protection of property. Communities are encouraged to achieve acceptable levels of risk by evaluating, communicating and managing risks, cost effective risk reduction, and monitoring and evaluation.

To achieve the purposes of the CDEMA, territorial authorities have a role in planning and implementing programmes. There are 16 CDEM Groups across the country. Each Group is required to prepare, consult on, and approve a civil defence emergency management group plan and review it every five years. Although there is scope for Group plans to include how heritage will be managed before, during and after a disaster, only a few actually mention the need to consider heritage.

9. Opportunities for heritage and engineering professionals to work together

The HNZPTA establishes a specific function of Heritage New Zealand: “in the event of a national or local emergency, to provide advice on heritage matters”. The review of the Civil Defence National Plan consulted on earlier this year has recognised this new role for Heritage New Zealand and also for the Ministry for Culture and Heritage. A civil defence emergency management group plan must not be inconsistent with the national civil defence emergency management strategy and must take account of Director's guidelines, codes, or technical standards. Four CDEM Group plans will be reviewed in 2014/15, nine in 2016/17 and three plans have recently been reviewed. This presents an opportunity for councils and civil defence and heritage experts to work together to ensure that heritage is taken account of in civil defence emergencies.

The requirement that a risk management plan is prepared for every proposed entry to the National Landmark List introduces the notion of risk management of heritage into legislation. Preparation of these risk management plans will require an interdisciplinary approach. An understanding of the heritage values of the proposed Landmark will be critical in setting objectives. Assessing risk and identifying risk management strategies will need input from heritage and engineering professions. Risk management plans will need to incorporate mechanisms for dealing with disasters, and will need to integrate with existing disaster response mechanisms.

Risk management plans for heritage will need to address reducing the vulnerability of heritage places to natural hazards. This presents the opportunity for dialogue between engineers and heritage specialists to find engineering solutions that take account of heritage values.

While risk management plans are only required for proposed Landmarks, in the longer term risk management should be addressed in conservation plans for all significant heritage places. This will be particularly important if the proposed amendments to the Building Act requiring strengthening of earthquake-prone heritage buildings within specified timeframes are enacted. Councils identify heritage in district plans and there is an opportunity to assess ways of reducing risk to heritage places through other council programmes such as flood protection work.

10. Conclusion

Natural hazards pose a threat to historic heritage as shown by both data on events and on loss of heritage. While a single major event can have a catastrophic effect on heritage, every year several significant heritage items are demolished and this adds up over time to a significant loss of heritage.

- We cannot influence the frequency or severity of natural hazards and our ability to reduce exposure is limited, but there are opportunities to reduce the vulnerability of buildings.
- While the current legislative framework protects historic heritage from human activities, it does not universally require that heritage items are maintained or upgraded to reduce their vulnerability to hazards.
- Proposed amendments to the Building Act would require councils to identify earthquake-prone buildings and owners to strengthen or demolish them within specified timeframes, with special provisions for heritage buildings.
- Changes to the Heritage New Zealand Act 2014 formalise the role of heritage professionals in the civil defence response
- Owners of properties proposed for inclusion on the National Landmarks list will need to prepare risk management plans.

In order to address the risks to heritage from natural hazards, engineers and heritage specialists will need to work together to find ways to reduce the vulnerability of heritage buildings that are cost-effective and provide an adequate level of protection while respecting the heritage values and heritage fabric of the place. Recent and proposed changes to legislation will challenge both the heritage and engineering communities, but also offers opportunities to collaborate and improve the risk management of New Zealand's historic heritage.

11. Acknowledgements
Michael Kelly and Nicola Jackson, for providing comments on a draft of the paper.

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SEISMIC STRENGTHENING AND RESTORATION OF CARGILL'S MONUMENT

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Abstract
Cargill's Monument was one of the first stone structures/monuments in Dunedin which required the skills of stonemasons and stone carvers capable of shaping complex neo-gothic forms. Built in 1864, it was designed by Otago's Provincial Engineer, Charles Swyer. Its level of execution far surpassed most of the basic houses and stone structures of the time. It is currently listed as having Category 1 historic place status with Heritage New Zealand Pouhere Taonga (formerly the New Zealand Historic Places Trust), meaning it has 'special or outstanding historical or cultural heritage significance or value'. This paper describes the process and methodology for the seismic strengthening design and construction, in conjunction with a full restoration of the now 150 year old historic monument. The main findings of this paper are that seismic strengthening of significant heritage structures requires early consultation with Heritage New Zealand to ensure consideration of conservation principles and requirements, allowing specific adaptation of strengthening methods to meet restoration and preservation objectives. This includes factors such as reversibility, resilience and minimal visual impact. It is also important and necessary to provide a higher level of input into construction methods and monitoring.

1. Introduction

The Cargill Monument was erected in the Octagon, Dunedin, in 1864. It commemorates Captain William Cargill, founder of the province of Otago. This paper describes and details the process and methodology behind the seismic strengthening design and construction of stone monuments in conjunction with restoration. The 150 year old Cargill's Monument is used as a case example. Historic stone monuments, by their very nature are potentially earthquake prone structures, relying mainly on mass and friction to resist sliding and overturning. In developing seismic strengthening solutions it is important to ensure the integrity of the structure and the visual impact of the works does not detract from the heritage and cultural values placed on the structure.

The Dunedin City Council (DCC) are to be acknowledged and commended for recognising the historic and cultural importance of Cargill's monument and in funding the seismic strengthening and restoration.

2. History

Cargill's Monument was one of the first stone structures/monuments in Dunedin that required the skills of stonemasons and stone carvers capable of shaping complex neo-gothic forms. Built in 1864, its level of execution far surpassed most of the basic houses and stone structures of the time.

It was designed by Otago's Provincial Engineer, Charles Swyer and is based on the larger Sir Walter Scott Memorial in Edinburgh, Scotland.

The monument was moved from its original site in the Octagon to its present site in the Exchange in 1886. [Figures 1 and 2].

Figure 1: Cargill's Monument on right c1900. (Photo: University of Otago Hocken Collections).

Figure 2: Intersection of Princes and Rattray Streets. Post 1910. (Photo: University of Otago Hocken Collection).

It is a very rare monument as it is built mainly out of solid sandstone blocks, unlike other large monuments that use a combination of brick, concrete and/or stone. It is listed as a Category 1 historic place (List no.4754) with Heritage New Zealand (known as the New Zealand Historic Places Trust prior to 2014), meaning it has 'special or outstanding historical or cultural heritage significance or value'.

3. Background

Initially this project started off as a maintenance and refurbishment project, as some of the stone elements had become loose or had fallen off due to weather erosion, vandalism and inappropriate maintenance (such as abrasive cleaning). Some stonework was also showing cracks and movement in and around the joints.

In 2008, the DCC decided it was prudent to do a seismic analysis of the structure which returned a result of around 14% of New Building Standard (NBS) which classed the monument as potentially earthquake prone. As a result, a decision was made by DCC to complete earthquake strengthening of the monument to a minimum 67% NBS in conjunction with the restoration and conservation of the monument. The strengthening design had to consider and meet the requirements of legislation relevant to the heritage and archaeological values of the site. These were the Historic Places Act 1993 (now the Heritage New Zealand Pouhere Taonga Act 2014 (HNZPTA)) and Resource Management Act 1991 (RMA).

Figure 3: Cargill’s Monument before restoration.

Heritage New Zealand administers the HNZPTA. Of relevance were the criteria for the legal definitions of an archaeological site, the legal protection for such sites, and the process for gaining permission to destroy, damage or modify such sites. This act contains a consent (authority) process for any work affecting archaeological sites. Under the act an archaeological site is defined as

(a) Any place in New Zealand, including any building or a structure (or part of building or structure), that:

i) was associated with human activity that occurred before 1900 or is the site of the wreck of any vessel where the wreck occurred before 1900; and

ii) provides or may provide through investigation by archaeological methods, evidence relating to the history of New Zealand (HNZPTA section 6).

(b) Includes a site for which a declaration is made under section 43 (1).

Any person who intended to carry out work that could modify or destroy an archaeological site, or to investigate a site using invasive archaeological techniques, has to first obtain authority from the Heritage New Zealand.

To comply with the HNZPTA and follow conservation best practice advice, the DCC had commissioned; a Condition Report and Conservation Specification by conservator Ian Bowman 1992 [1]; a Condition and Specification report for repair and restoration by Marcus Wainwright 2009 [6]; and the Archaeological Assessment Report by Guy & Erin Williams dated November 2011 [7].

The Wainwright report [6] identified damage to stonework from abrasive cleaning and from water ingress through the joints, causing the original metal ties to corrode causing further damage especially around the upper flying buttresses and lower vault arches. The Williams report [7] made recommendations for repair and restoration works which included the systematic deconstruction of the upper part of the monument to enable removal of the faulted steel armature and damaged stones. It also revealed several archaeological features in the immediate vicinity of the structure, which needed to be considered if the ground was to be disturbed. In the event of disturbance below the monument it was possible that evidence of earlier subterranean public toilets (said to have been filled in with sand and broken toilets), remains of the former Mechanics’ Institute, and pre-1900 use of the site by both Europeans and Maori, could be encountered.

Williams [7] made the following recommendations:

- As a first principle, every practical effort should be made to avoid damage to any archaeological site, whether known or discovered during development.

- In the advent of site disturbance works being proposed, an archaeological authority under the [HNZTPA] for those site disturbance works should be applied for and obtained from [Heritage New Zealand].
- No site disturbance works should occur prior to the issue of an Archaeological Authority, and all works undertaken thereafter should be in accordance with the conditions of the authority that is granted.
- In the event of any site disturbance works being undertaken, this should be kept to an absolute minimum and be directed and monitored by a [Heritage New Zealand] approved archaeologist.
- All contractors engaged in site disturbance works should be briefed and familiar with the conditions of the authority, and be prepared to abide by those conditions.
- All contractors engaged in site disturbance works should be briefed on the nature and extent of the archaeological sites in the development area, as well as any others in the vicinity of the works site.
- In the advent of archaeological material being discovered, all works in the vicinity of the discovery should cease, the area of the discovery isolated by marker tapes or protective barriers, and the monitoring archaeologist arrange for actions to be undertaken that are appropriate to the significance of the discovery.
- If at any stage during the excavation or site works Maori material is discovered, local iwi should be consulted in the first instance. If any Maori material does exist in the area, damage to this should be minimized. Any pre-European artefacts will be, prima facie, property of the Crown, and should be submitted to Otago Museum.

The above conditions were followed but as there was minimal disturbance of the ground (four micro piles) no items of archaeological importance were discovered or disturbed.

Further design considerations required, were that the mortar and stone had to be assessed to determine material properties including density, compression and shear strengths.

A full topographic survey was carried out to accurately determine structural dimensions. The monument had two levels of stone arches and cross sections progressively narrowing to the intricate spire at the top. A variety of finials and grotesques [Figures 4 and 5] adorn the structure and these needed to be included in the strengthening design.

Figure 4: Grotesques and lower arch.

Throughout the project, consultation with Heritage New Zealand was maintained to ensure the integrity and reversibility of the proposed and eventual work, and to ensure strengthening measures and implementation was undertaken to an acceptable restorative standard.

Figure 5: Decorated finials and upper arch.

4. Challenge

The monument, approximately 12m in height, is highly ornate and decorative. These features do not allow for external strengthening. Therefore any strengthening had to be placed unobtrusively within or behind the stone. The structural strengthening was based on a specified design life of 100 years, so had to be durable and also reversible to facilitate future repairs or replacement.

The restoration part of the project required removal of the original steel cross ties that had varying states of corrosion and replacing these with highly protected metal (Thermal zinc spray and a high build epoxy coating).

The original stone needed to be sourced for the repair and replacement of sections and to determine the physical properties. The original stone was Tasmanian sandstone [7] and was unfortunately no longer available [2]. However the replacement stone was sourced from Australia and was the closest that could be matched to the original stone.

Collaboration with the restoration stone mason, Marcus Wainwright, was essential in planning the project to determine what strengthening system would be possible and acceptable within the conservation and restoration process. Advice was sought as to probable historic construction method and the internal stone size and configuration.

5. Design

Strengthening analysis of the structure was undertaken in accordance with New Zealand standards NZS 1170.0 and NZS1170.5 Structural Design Actions [5].
Design assumptions used were as follows;
Soil Type C – Shallow soil sites
Ductility = 1.5
Importance level 2
Hazard Factor, Z= 0.13
Design life = 100 years
ULS Annual Probability of exceedance = 1/1000
SLS Annual Probability of exceedance = 1/25
ULS Return Period Factor, Ru = 1.3
SLS Return Period Factor, Rs = 0.25
Near fault factor, N = 1.0
ULS Seismic co-efficient = 0.25
SLS Seismic co-efficient = 0.05

Material Properties
Sandstone density 2250 kg/m3
Sandstone Compressive Strength (~20MPa)
Natural Hydraulic Lime Mortar strength 8MPa
Macalloy bars yield strength 650MPa

The original monument stonework was structured around four main buttresses and pillars, reducing in size as they ascended, being connected at various levels through arches and metal cross ties.

Various strengthening options were considered and it was decided that the preferred solution was to provide corrosion resistant steel rods dowelled through the stone. The rods were bolted to cross plates or beams at various levels, clamping the structure in place. At the base the rods were bolted to a steel box beam placed through cored stone and held down with tension piles.

The monument's structure was analysed using Microstran computer analysis software to determine the expected design forces within each of the structural elements. This was conducted by modelling a frame structure that consisted of equivalent sized concrete members replicating the stone dimensions and properties in conjunction with the new central steel tie elements [Figure 6]. The analysis used the equivalent static method with the forces applied at the six levels throughout the monument where diaphragm action was expected to occur with the installation of the new steel plate members.

The tensile forces are transferred through the structure by the installation of the vertical steel tie members located within holes cored through the stone elements, with each of these tension ties restrained at the various levels by the cross braced plates. The tension ties were introduced throughout the height of the monument to provide a continuous load path within the stone all the way down to the base of the structure.

Four new micro-pile foundations were installed below the monument to resist any uplift forces that resulted from a significant seismic event where the self-weight of the monument alone was insufficient. The micro-piles were unable to be located directly below the lower level tension ties. Therefore, a steel box section cross beam was installed to transfer the tensile loads from the monument back into the newly installed micro-pile foundations through bending and shear. Shear forces within the structure are resisted by the shear strength of the lime mortar joints, tie rods and friction due to the mass of stone above.

Prior to the strengthening works the monument was assessed as having a nominal ductility of 1.0 (non-ductile). The strengthening design conservatively used a ductility factor of 1.5. This was based on the installation of the steel tie members that were de-bonded from the surrounding grout by wrapping them in Denso tape, thus allowing the potential to yield and elongate between the adjacent steel plates located within each level of the monument. Seismic energy will potentially also dissipate through the bending of the steel base box beams and individual steel plates located at each level as a result of the offsets between the steel tension ties within various sections of the monument.

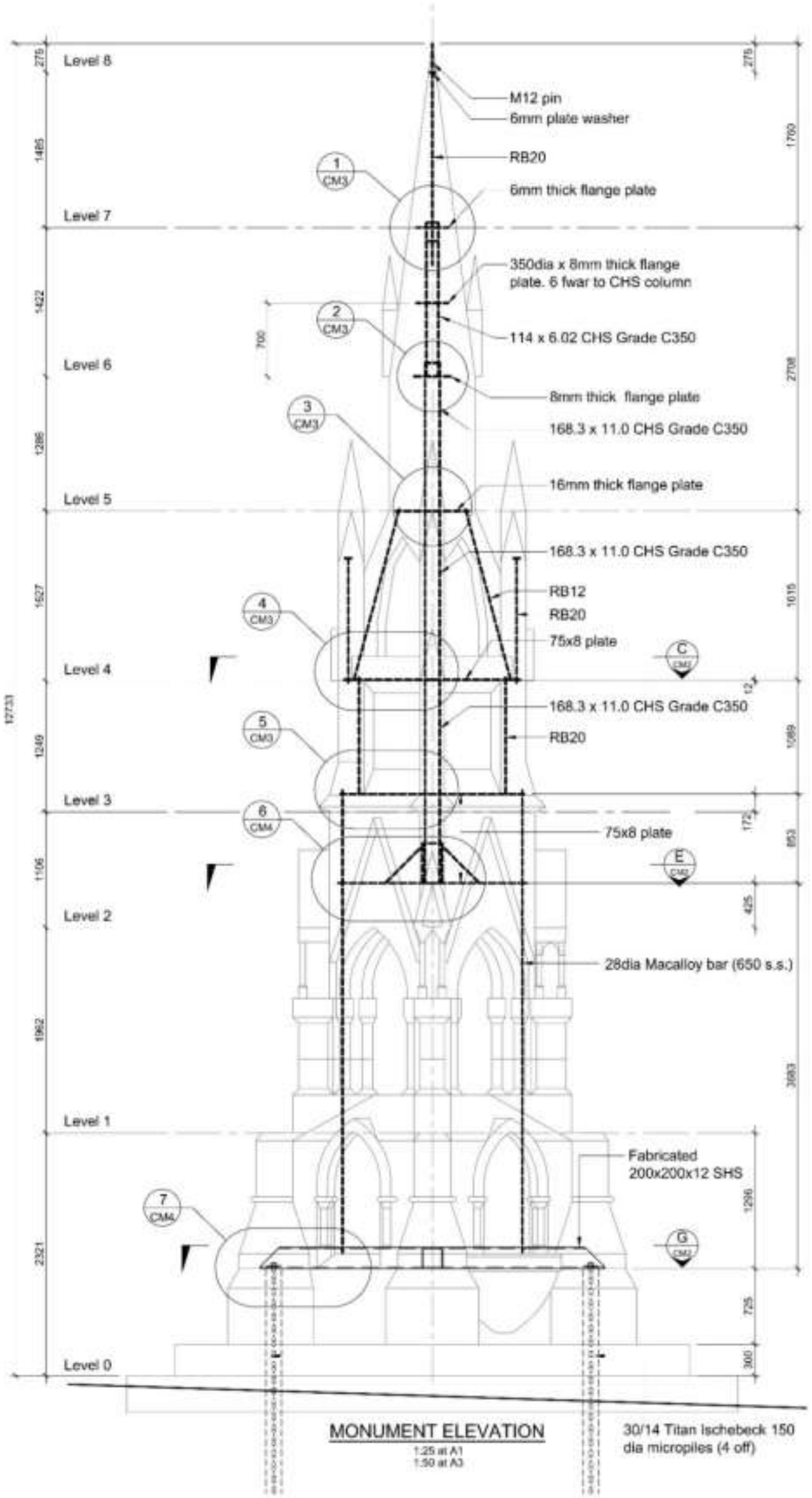

Figure 6: Seismic strengthening frame model.

After a Heritage New Zealand commissioned review of the initial design and subsequent comments by Heritage Engineer Win Clark, additional options were considered including the potential for the monument to rock under full seismic load allowing further energy dissipation. NZS1170.5:2004 [5] Section 6.6 addresses design of rocking structures by requiring that '…the actions of the structure shall be determined by a special study'

However the rocking design procedure we adopted followed simplified guidelines by Kelly [3] and Priestley et al [4]. In analysing this option it was found that the seismic force required to generate uplift was high; due to the structure geometry and the fact that the monument was located in a low seismic zone. Also to limit potential non-structural damage it was decided to limit rocking displacement by use of the un-bonded Macalloy rods combined with thick bearing pads between the base beams and the four Micro-piles.

The governing design factor was the shear strength of the mortar and steel bar system. The solution to the rod/stone interaction was achieved by using a natural hydraulic lime mortar around the tie rods. This enabled the rods and structure to move with a degree of separation and flexibility, allowing the rods to yield in a large seismic event. The lime based mortar also allowed the stone to breathe and move as original; reducing potential stress in the stone.

Above the lower arch there was sufficient internal void to enable a central steel column to provide lateral restraint from plates and rods at various levels [Figures 8 and 9].

The seismic resisting mechanism has been designed to exceed 67%NBS but also encompasses future resilience with almost all elements able to be repaired or replaced after a seismic event.

6. Execution

Figure 7: Dismantling revealing original corroded tie bars.

The monument was carefully dismantled in late 2011 to a low level just above the lower arches, removing all corroding steel. [Figure 7]. The stone elements removed were transported to a workshop for repair and for coring vertical holes to fit proposed rods.

The corner stones at the base of the monument were also temporarily removed to allow for the micro piling to be undertaken.

The reconstruction phase followed in 2012 to re-build the steel/stone framework structure with the restored stonework. The reconstruction team of specialist stonemasons and engineers were appointed and combined to achieve the high standards and care required. Whilst the concept was simple to visualise on paper, each section/level of steel had to be site measured and tailored to fit with templates during the monument's re-build.

Further limitations/alterations to the strengthening plan were:

- Thickness of stone to allow for the central coring, this reduced further up the monument especially in the location of the curved arches.
- The ability to cut the stone without damaging its integrity,
- The capability of the steel workers and stonemasons to actually lift, install and place the steel; and finally
- The requirement for reversibility, where natural hydraulic lime and bolting was used instead of cement, epoxy and welding.

Figure 8: Reconstruction.

Figure 9: Re-Construction plates and rods.

Due to variations in stone configuration from that assumed before dismantling, the internal design dimensions had to be amended as each section was exposed. Further design considerations that affected the final solution were:

- The seismic demand was reduced by removing the stone rubble mass located within the enclosed area above the first arch.
- Stainless steel Macalloy bars were used in the lower section for durability reasons, as well as the fact that they had a higher ductility than the alternative bars that were proposed.
- Originally all members were to be stainless steel but it was decided to use galvanised bars wrapped in Denso tape above the lower arch to provide an equivalent durability at reduced cost. The steel plates were protected with thermal zinc spray and a high build epoxy coating.
- Wrapping in Denso tape also ensured all bars were de-bonded from the surrounding grout, allowing them to yield if required.
- The cored voids within the stone were flooded with water before grouting to ensure that the surrounding stone was saturated. This ensured that the moisture within the grout did not transfer into the surrounding stone which reduced the potential for shrinkage within the grout surrounding the steel rods.

Figure 10: New carved stone Grotesques.

7. Conclusion

The structural strengthening of this important heritage monument is unique within the country. The restoration works and strengthening required the monument to be partially dismantled and rebuilt. The installation of the steel rods and sections within the stone posed on-going challenges mainly due to the fine tolerances required, but were competently solved on site with satisfying results.

This report has highlighted the fact that successful seismic strengthening of significant heritage structures requires early consultation and coordination with conservatory principles and requirements, and Heritage New Zealand. This allows site specific adaptation of existing strengthening methods to be developed which meet restoration and preservation objectives. These include factors such as reversibility, resilience and minimal visual impact. It is also important and necessary to provide a higher level of input into construction methods and monitoring.

In this way the Cargill's Monument seismic strengthening and restoration project has ensured a lasting legacy for many years to come.

Figure 11: Restored and Strengthened Monument.

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