AUSTRALASIAN ENGINEERING HERITAGE CONFERENCE PAPERS 2022

engineering new zealand HERITAGE

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STRENGTHENING AND REFURBISHING HERITAGE STRUCTURES

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STRENGTHENING AND REFURBISHING HERITAGE STRUCTURES: WRITER BIOS

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THE TALE OF TWO BRIDGES: HOW UNDERSTANDING HERITAGE SIGNIFICANCE CAN GUIDE THE TREATMENT OF OUR COUNTRY'S UNIQUE STRUCTURES

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Summary: The Rakaia Gorge No.1 Bridge is an internationally unique Bollman-style truss bridge built 1880-82. The Opawa Bridge in Blenheim was the first bowstring arch truss bridges built in reinforced concrete to be constructed in New Zealand in 1917. Both are Category 1 listed historic structures. Increasing traffic weights and volumes, and ongoing maintenance challenges, mean that these bridges have both been required to adapt in different ways. This paper will discuss (from the Conservation Architect's perspective) two different approaches taken to finding solutions that balanced heritage and engineering constraints in accordance with Conservation Management Plans, and with a little compromise on both sides.

Bridge, Conservation Management Plan, Conservation Plan, Engineering Heritage, Restoration, Significance

INTRODUCTION

The Rakaia Gorge No.1 Bridge is an internationally unique Bollman-style truss bridge built 1880-82. After almost 140 years of use, and ever-increasing traffic weights and volumes, the bridge deck was becoming severely deteriorated. Replacement or "duplication" was not an option in this case; and the initial engineering solution proposed failed to take account of the structure's heritage values. This meant that the project had to "go back to the drawing board", with a shift in focus that placed heritage significance at the centre. This year (2021), the resulting upgrade was recognised with a SESOC Award for Structural Heritage.

The Opawa Bridge in Blenheim was one of the first bowstring arch bridges in reinforced concrete to be built in New Zealand and is a significant local landmark (known as the 'Banana Bridge'). However, the narrow lanes and complex condition issues prompted construction of a replacement bridge. Instead of demolishing the existing bridge, a decision was made to transition it to active modes (walking and cycling), prior to which it underwent some long-awaited repair and restoration. The addition of interpretation panels telling the story of the bridge further emphasise the importance of its retention and ongoing accessibility to the public.

This paper will discuss (from the Conservation Architect's perspective) two different ways in which solutions that balanced heritage and engineering constraints were achieved in accordance with Conservation Management Plans, with a little compromise on both sides.

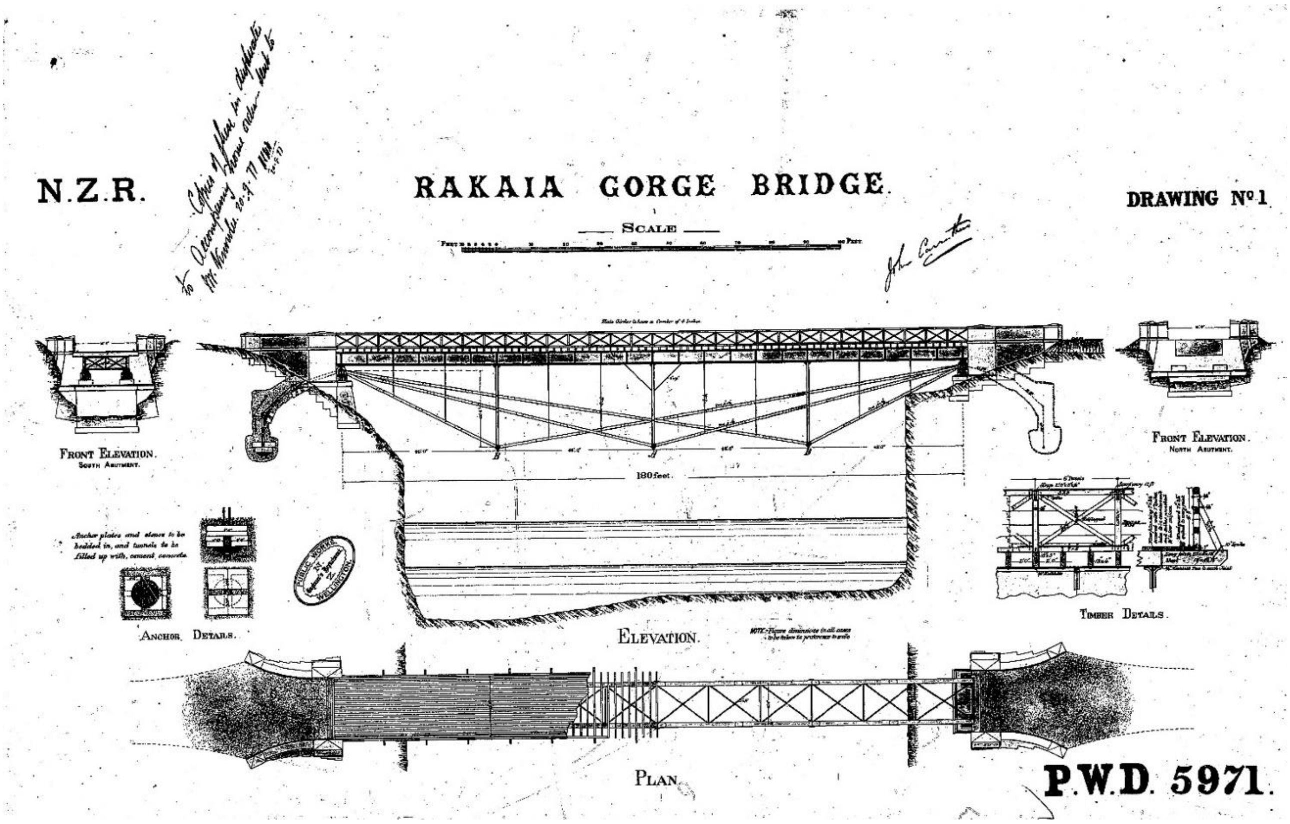
RAKAIA GORGE NO.1 BRIDGE

Background

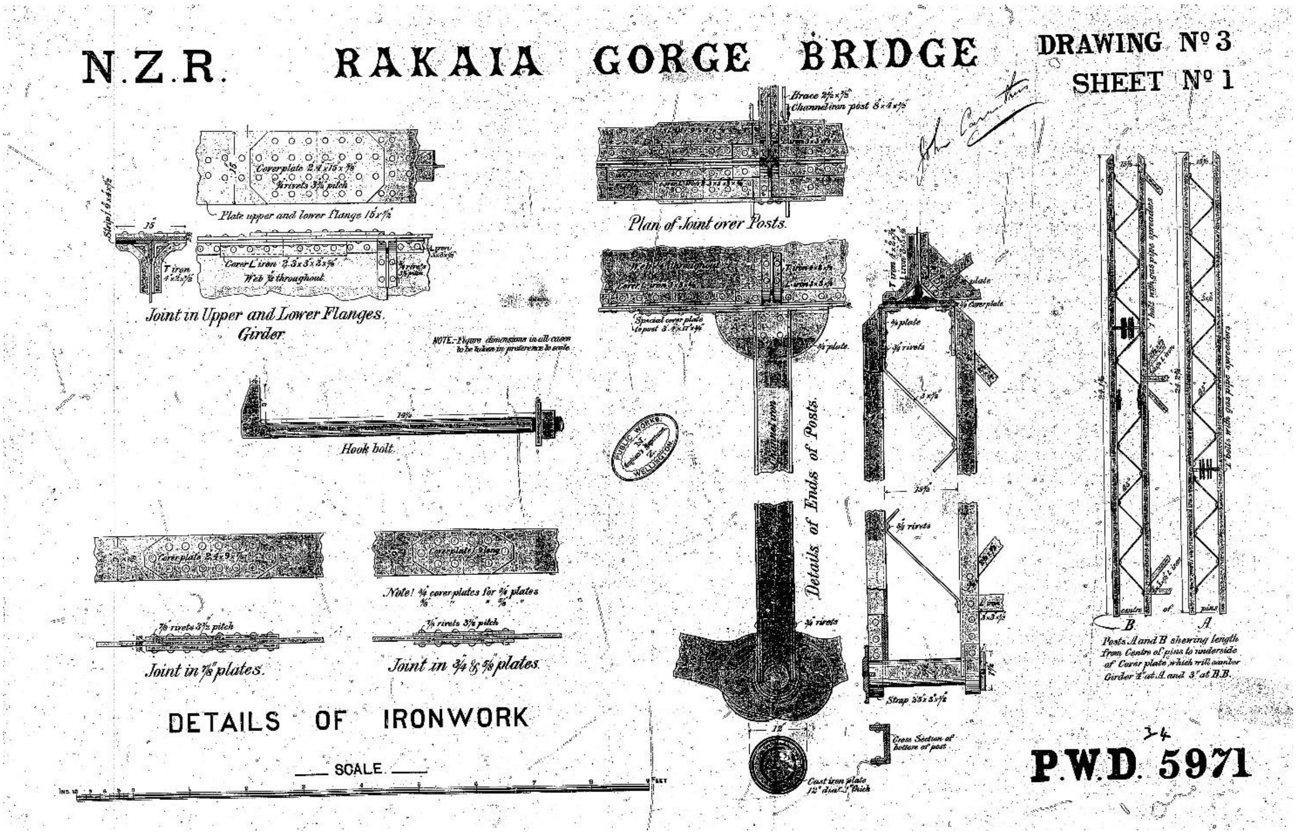
The Rakaia Gorge No. 1 Bridge was constructed in 1882 under the supervision of the Public Works Department (PWD). Its unique design has historically led some to believe that it was conceived overseas – most likely in the United States, where experiments in bridge engineering during the 1850s had led to the development of several new truss designs [1]. The design of the Rakaia Gorge No.1 Bridge draws particularly on the works of Wendel Bollman and Albert Fink, both of whom worked on the ground-breaking Baltimore and Ohio Railway. However, research has proven that the design of the Rakaia Gorge No.1 Bridge was definitely the work of the New Zealand PWD; though it is not certain exactly who conceived the design.

The Rakaia Gorge No.1 Bridge truss differs from the Bollman and Fink trusses in that the diagonal ties are anchored at each end within concrete-filled sockets that are tunnelled into the rock outcrops on which the abutments are founded. The girders are supported completely independently on cast iron pedestals and do not act as a compression chord; so, strictly speaking, the structure is not actually a truss at all.

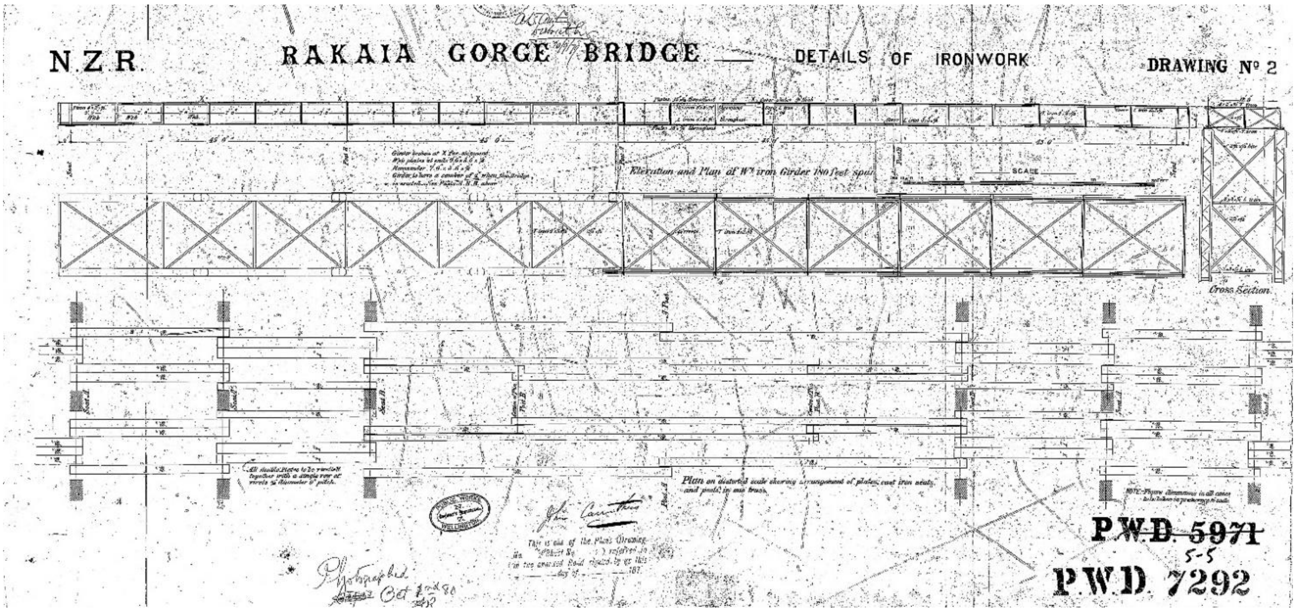
Severe winds in 1889 resulted in damage to the bridge truss, and the Public Works Department determined that additional bracing was required. However, the installation of this bracing was delayed, and subsequent maintenance was often deferred, because the Ashburton and Selwyn County Councils [2] disagreed over which authority was responsible for the bridge [3]. Any maintenance that was carried out was sporadic and generally undocumented, unless it was important enough to make the newspapers [4]. This continued until the route was designated a State Highway and the bridge passed into the control of Transit New Zealand (now the New Zealand Transport Agency). The effects of the harsh environmental conditions, and a considerable increase in the weight and number of vehicles crossing the bridge, exacerbated the problems caused by deferred maintenance.



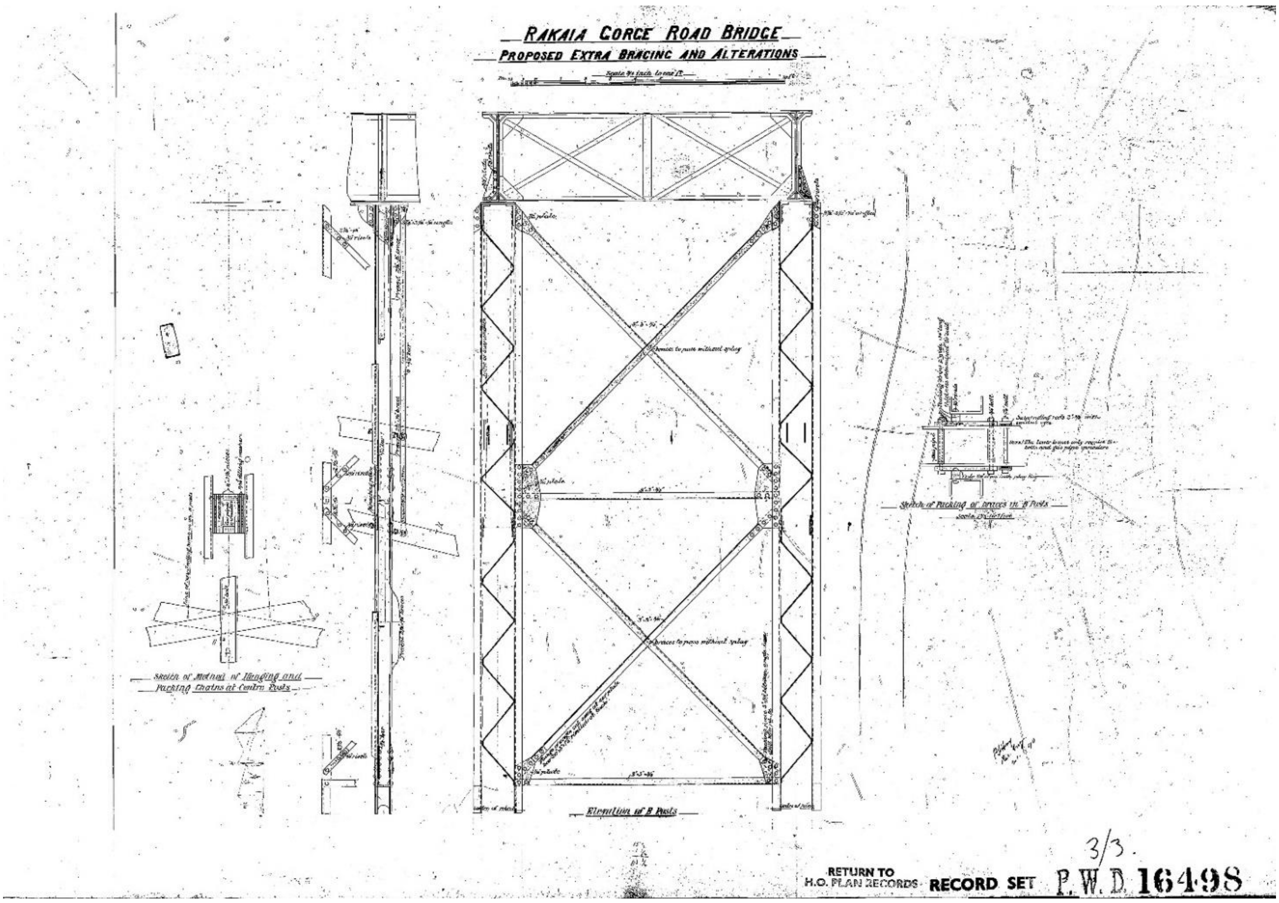
[Figure 1] Original drawings for the Rakaia Gorge No. 1 Bridge showing the overall structure in plan and elevation. Source: Archives New Zealand PWD 5971



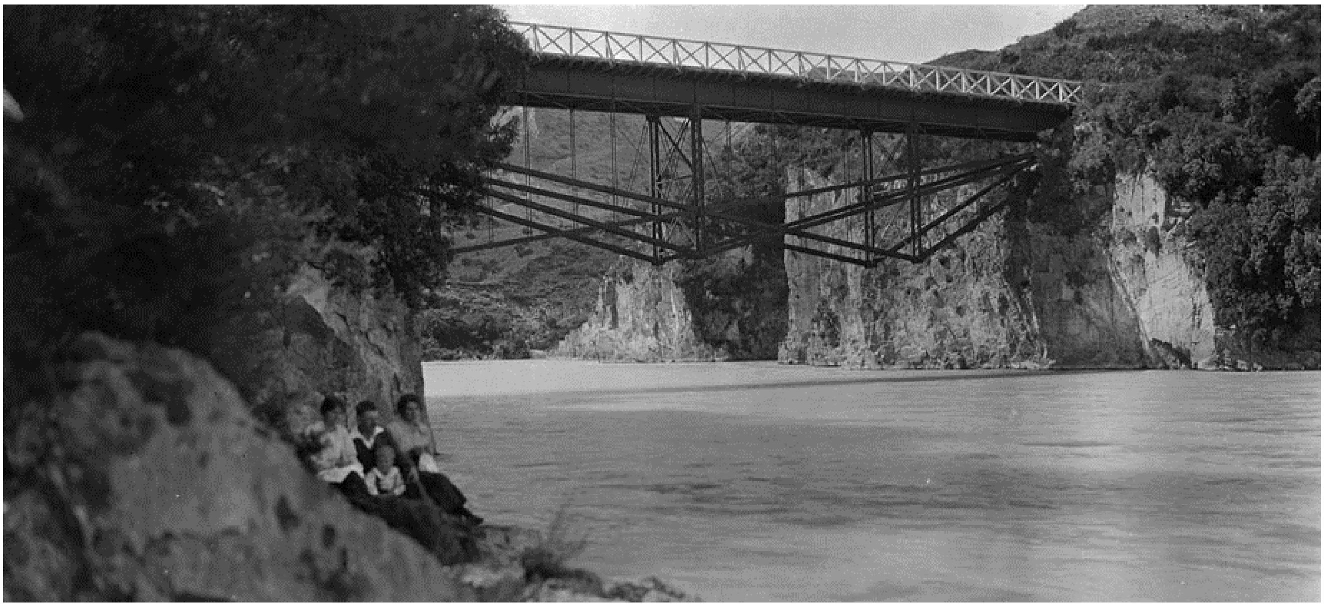
[Figure 2] Original drawings for the Rakaia Gorge No. 1 Bridge showing some of the ironwork details. Source: Archives New Zealand PWD 5971



[Figure 3] Original drawings for the Rakaia Gorge No. 1 Bridge showing some of the ironwork details. Source: Archives New Zealand PWD 7292



[Figure 4] Drawings for the Rakaia Gorge No. 1 Bridge showing some of the additional wind bracing details, 1889. Source: Archives New Zealand PWD 16498



[Figure 5] Rakaia Gorge No. 1 Bridge, date unknown. Source: Battson Series 4, Sir George Grey Special Collections, Auckland Libraries, Record ID: 35-R2137

[Figure 6] Rakaia Gorge Bridges, photographed by E. Wheeler & Son, date unknown. Note the original timber No.2 Bridge to the left before its replacement. Source: Hocken Collections Asset ID 26089

[Figure 7] Repairs to the Rakaia Gorge Bridge in 1986. The repairs that were being carried out at this time are not documented. Source: Christchurch Star (CCL-StarP-03997A)

The Problem

WSP (formerly Opus) monitored the condition of the Rakaia Gorge No.1 Bridge for many years as the Transport Agency's Structures Management Consultant (SMC) for Canterbury. By 2016, a number of transoms had been augment-strengthened; the loading capacity of the bridge had been limited, and the carriageway restricted to a width of 3.5m using timber kerbs in an attempt to prevent eccentric loading. Timber-drilling investigations were indicating that the 75 mm thick diagonal softwood running planks and 80 mm thick longitudinal hardwood deck planks beneath, had deteriorated to the extent that it was no longer considered practical or sufficient to remediate the decay without further compromising on the live load capacity. Further, the instability of the surrounding rock outcrop, potential unseating of the girders from the pedestals, unclear longitudinal restraint system and failure of the bracing meant the bridge was seismically vulnerable. Consequently, it was concluded that truss should be strengthened and the bridge deck replaced. Replacement of the deck would require the timber balustrades to be removed, at least temporarily. Given their poor condition, and their non-compliance with current bridge safety standards, it was assumed that the balustrades would also be replaced.

Design for the strengthening and deck replacement was commenced by WSP bridge engineers in 2016. As the documentation was being completed, the design team approached WSP archaeologists to prepare an application for an Archaeological Authority for the works, which was required under the Heritage New Zealand Pouhere Taonga Act [5].

At that time, the proposal was to remove the entire deck, including the balustrades above and the transoms below, and replace everything. The new transoms would be steel, the deck would be a NiuDeck system, the balustrades would be metal, and crash rails would be added.

Recognising the heritage status of the bridge, and that engagement with Heritage New Zealand Pouhere Taonga's architectural advisors would be required due to its Category 1 listing, the archaeologists questioned whether the design team had sought the advice of a heritage consultant. It was at this point that I was brought to the table, in the hope that I would give a rubber stamp to the proposal and obtain the support of HNZPT.

It was immediately apparent that the proposed design did not conform with best practice heritage conservation. Beyond the truss, the heritage significance of the existing fabric had not been assessed or considered. An initial evaluation of the significance of fabric and a high level assessment of effects on each of the bridge components was undertaken to demonstrate where the proposed design would result in negative effects on heritage. The fundamental changes that the proposal would make to the original bridge design, and the wholesale removal of all historic timber fabric proposed, would have a significant adverse effect on the heritage values of the bridge that could not be justified on the grounds of engineering safety without further investigation and testing of options.

As a result of this, the design work, consents, and forthcoming construction programme were put on hold; and a Conservation Management Plan was commissioned. Conservation Management Plans explain why a place is significant, what that significance is, and how to manage the place in accordance with that significance. A fundamental part of good conservation practice, Conservation Management Plans are imperative for the informed and appropriate treatment, and ongoing maintenance, of a historic structure.

Once a complete draft of the Conservation Management Plan had been prepared, the design team then came back together, along with myself, Transport Agency Principal Heritage Specialist Ann Neill, and representatives of HNZPT to interrogate the proposed design and its compliance with the policies of the Plan, and to see how the policies could inform changes that would avoid or minimise the negative impacts on the bridge's heritage significance.

Balancing the heritage, engineering and safety performance requirements did not come without compromise. It was not possible to avoid all negative effects on the bridge's heritage values, nor was it possible to achieve a design that was compliant with the Transport Agency's standards for new bridges. However, understanding the significance of the bridge and its fabric, and the appropriate levels of intervention based on this significance, was critical to the development of a balanced solution. This required the design team to "go back to the drawing board" with regards to some aspects of the design, and pushed the start date for the project into the following year. If a Conservation Management Plan had been undertaken before design work had started, the programme delays would have been avoided.

The Outcome

The original hardwood transoms were a highly visual element of the bridge when viewed from the beach below and from the approaches on either side. Along with the deck planks, the transoms were identified as being significantly decayed (Figure 8). The engineers' original proposal to replace the timbers with new steel transoms at wider spacings was considered to be necessary to reduce the overall weight of the deck and thereby improve the resilience of the bridge. To maintain the aesthetic of the original design, timber salvaged from the original transoms was spliced to the ends (Figure 11). Where there were no steel transoms to splice to (due to the wider spacing), dummy transom ends were attached to retain the historic appearance of the bridge (Figure 10). The new steel transoms were dated to record the introduction of new fabric.

Left: [Figure 8] The original hardwood transoms, showing signs of decay and microbiological growth.
Right: [Figure 9] The new spliced transoms.

Left: [Figure 10] Transoms without steel substructure attached to the deck to retain the aesthetic features of the bridge.
Right: [Figure 11] The new spliced transoms – steel with hardwood ends.

The mass concrete parapets at each end of the bridge were in poor condition with widespread cracking, moss growing out of the cracks, flaking paint and areas of graffiti carved into the rendered finish (Figure 12). The engineers' proposed solution was to inject a high strength mortar; however, this would likely cause future problems as the repairs would perform very differently to the original low-strength concrete. Samples were taken from the parapets to confirm their composition and compressive strength, and this was used as the basis for the selection of specialised repair products. The parapets were then completely stripped of paint and render, repaired, re-rendered and re-painted white. Areas of graffiti deemed to be of heritage value were retained as part of the refurbishment and the new render was placed around and plastered to match (Figure 13). In addition to the conservation related benefits, the restoration and painting improved the visibility of the parapets and hence improved the safety of the road user.

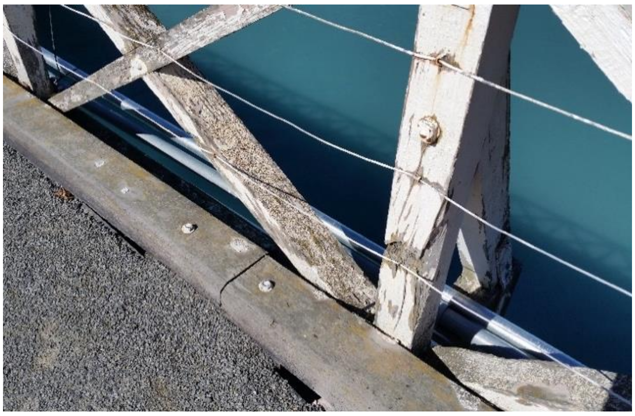
Left: [Figure 12] The damaged parapets prior to repair.
Right: [Figure 13] Re-plastering of the parapets.

Left: [Figure 14] The repaired parapets, repainted white to improve visibility.
Right: [Figure 15] The repaired parapets, with retained historic graffiti.

As part of the Conservation Management Plan, an analysis of the existing balustrades was undertaken to determine how many original members remained in situ, and exactly where these were located. This revealed that a significant number of the timber members within the balustrade had been replaced sporadically over time; and replacement timbers were of varying ages and condition (Figure 16). Joints between original and replacement timbers were often poor, and some members were dislodged. Rot and organic growth were widespread (Figure 17). A similar extent of replacement and decay was evident in the iron straps and fixings; and the fencing wire fixed to the balustrade was gouging the timber. Carved graffiti was widespread; however, some of this dated as far back as the 1930s. Rather than replacing the balustrades with new metal barriers as had been proposed, the balustrades were taken apart in numbered sections and reconstructed using as many of the historic components as their condition permitted. Where this was not possible, new hardwood was used, with joints detailed to match the original as closely as possible (Figure 18). The new material was date stamped to indicate the introduction of modern fabric (Figure 25 – Figure 26). The historic straps and fixings were cleaned, repainted and reinstated; and new straps and fixings were made to match where required.

[Figure 16] Rakaia Gorge No.1 Bridge timber balustrade assessment, prepared by WSP (C. Stevens) 2016

Left: [Figure 17] The damaged balustrade prior to repair.
Right: [Figure 18] The repaired balustrade.



Left: [Figure 19] The damaged balustrade and timber kerbing prior to repair.
Right: [Figure 20] The repaired balustrade, with timber kerbing.

Left: [Figure 21] Removal of the historic balustrades.
Right: [Figure 22] The balustrade was deconstructed using conservation best practice - each member individually numbered, and its condition assessed for reuse.

Left: [Figure 23] Reconstruction of balustrades, incorporating historic fabric where possible.
Right: [Figure 24] Reinstatement of balustrades on site.

Left: [Figure 25] Date stamping of the new balustrade.
Right: [Figure 26] Installation of the new balustrade with interlocking design.

The original longitudinal timber decking which remained underneath a modern layer of timber and seal was removed due to advanced decay identified in the Special Inspections, and replaced with NiuDeck. This significantly reduced the weight of the deck, reducing stress on the superstructure below, and resolved water drainage issues which were negatively impacting the structure. The deck system sits longitudinally between the transoms but is not visible, and therefore had minimal aesthetic impact. Salvaged timber decking was donated to an adjacent landowner for construction of signage and furniture along a walking track from which the bridge is visible.

Left: [Figure 27] The original longitudinal decking, viewed from underneath the bridge, showing water damage.
Right: [Figure 28] Some of the original decayed decking members being removed.

Left: [Figure 29] The walking track sign on the Taniwha Track uses original hardwood transoms from the bridge.
Right: [Figure 30] Hardwood benches made from the original transoms and deck planks, gifted to the Taniwha Track.

[Figure 31] The Rakaia Gorge No.1 Bridge at completion of the project.

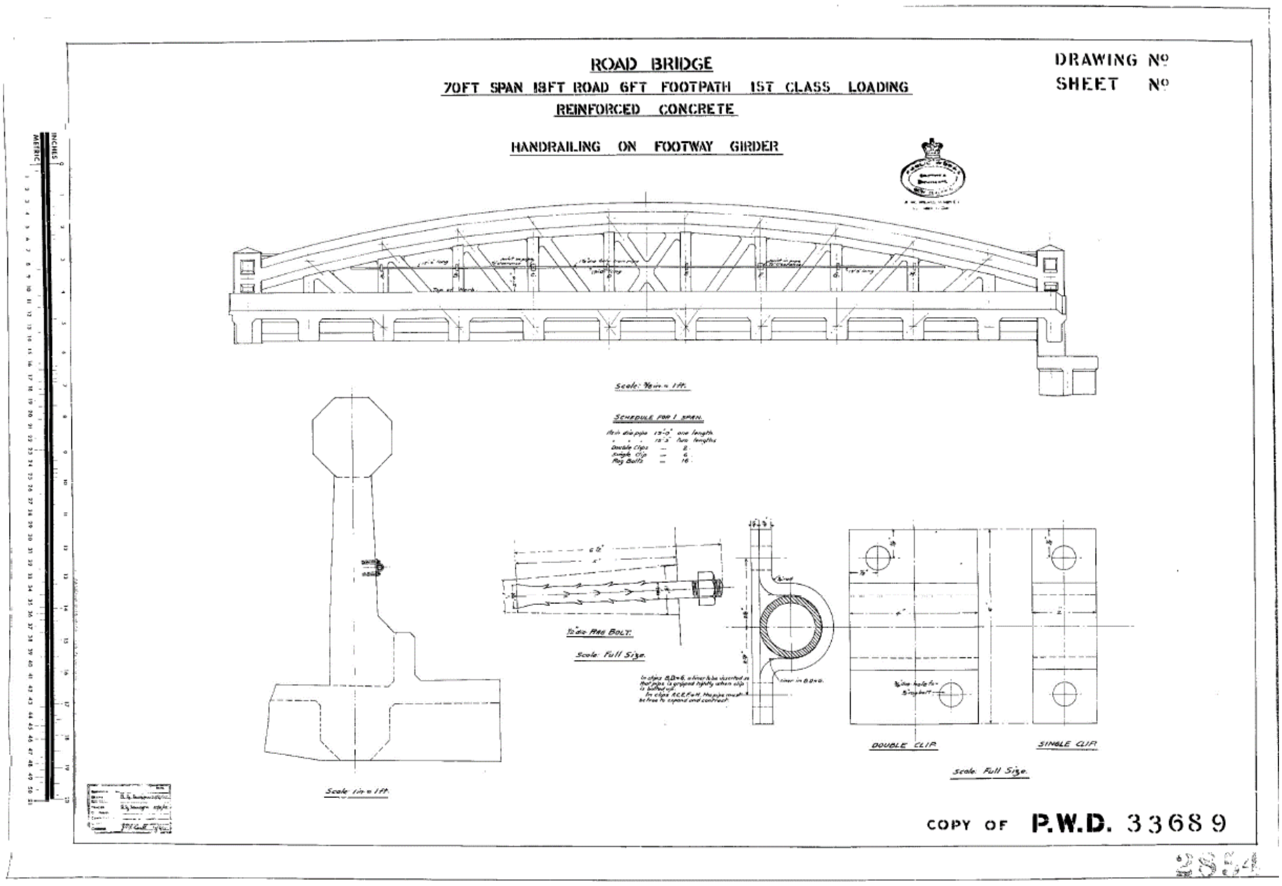
[Figure 32] The Rakaia Gorge No.1 Bridge at completion of the project.

THE OPAWA BRIDGE

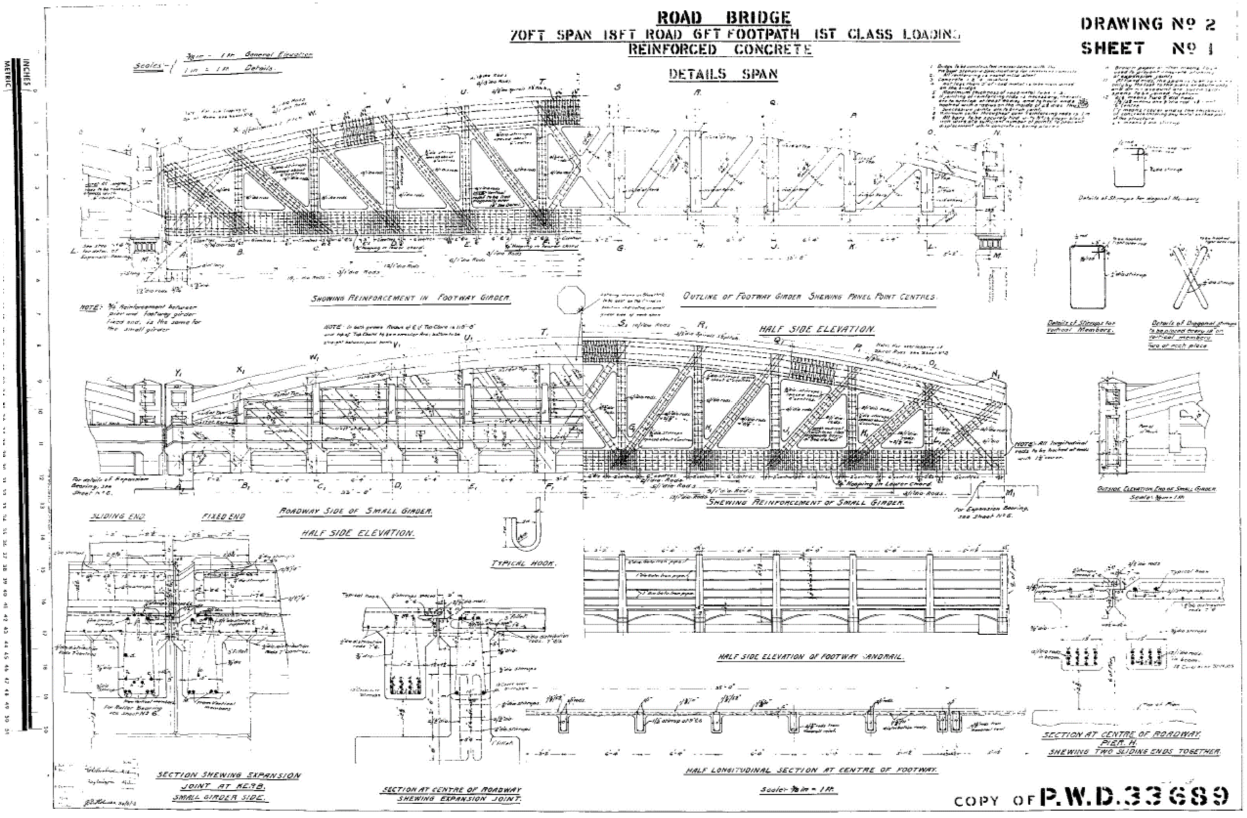
Background

The Opawa Bridge was constructed between 1915 and 1917, and replaced an earlier bridge across the Ōpaoa River at Grove Road in Blenheim which had been washed away forty years before. It was designed by engineer J. D. Holmes, under the supervision of his father R. W. Holmes, Engineer-in-Chief at the PWD.

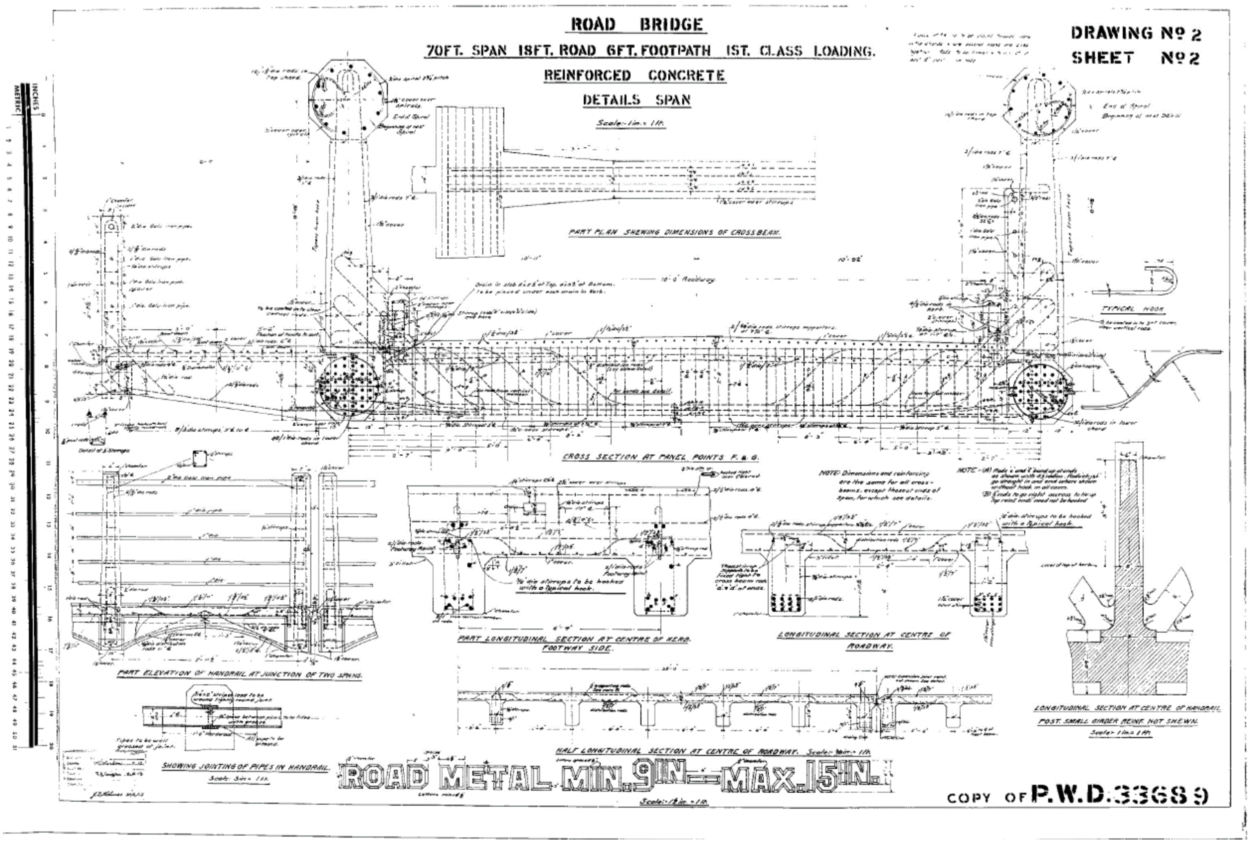
The structure comprises eight reinforced concrete bowstring arch trusses either side, with a central deck of 5.5m for road traffic and a cantilevered pedestrian walkway on the eastern side. The bowstring arch trusses are an adaptation of the Pratt truss [6], with crossed members in the centre and the top chord forming a true arc. Loads on the bridge deck are carried up the hangers to the top chord of each truss; and the trusses are tied at the base with a bottom chord that prevents them from spreading. Generally, each span is simply supported, fixed to the reinforced concrete piers at one end, and resting on steel bearings fixed to the concrete piers at the other. This created slip joints between the spans, allowing the bridge to move under live loads and during earthquakes, and accommodate thermal variations [7]. Like the Rakaia Gorge No.1 Bridge, the Opawa Bridge is a striking example of engineering that was highly innovative at the time it was conceived.



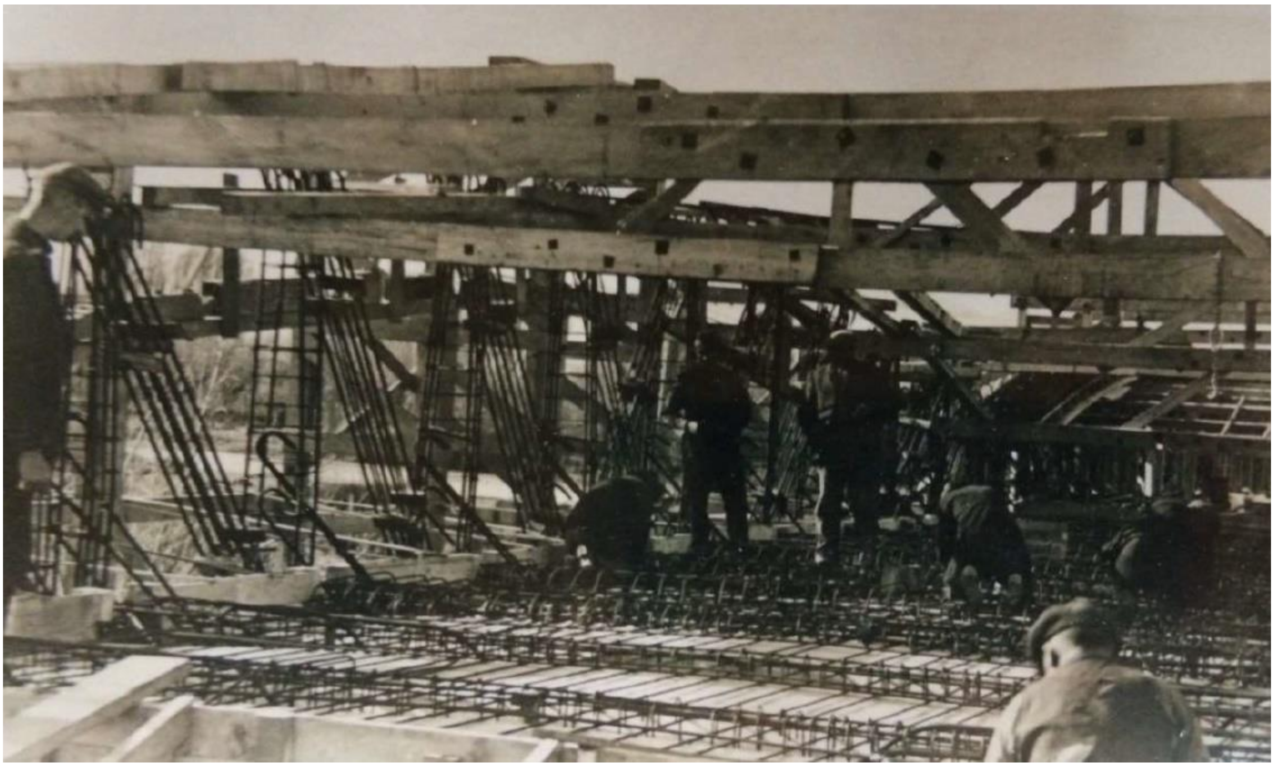
[Figure 33] Original drawings for the Opawa Bridge showing the bowstring arch truss. Source: Archives New Zealand PWD 33689



[Figure 34] Original drawings for the Opawa Bridge showing the reinforcement of the bowstring arch truss. Source: Archives New Zealand PWD 33689



[Figure 35] Original drawings for the Opawa Bridge showing the reinforcement of the bowstring arch truss and deck. Source: Archives New Zealand PWD 33689



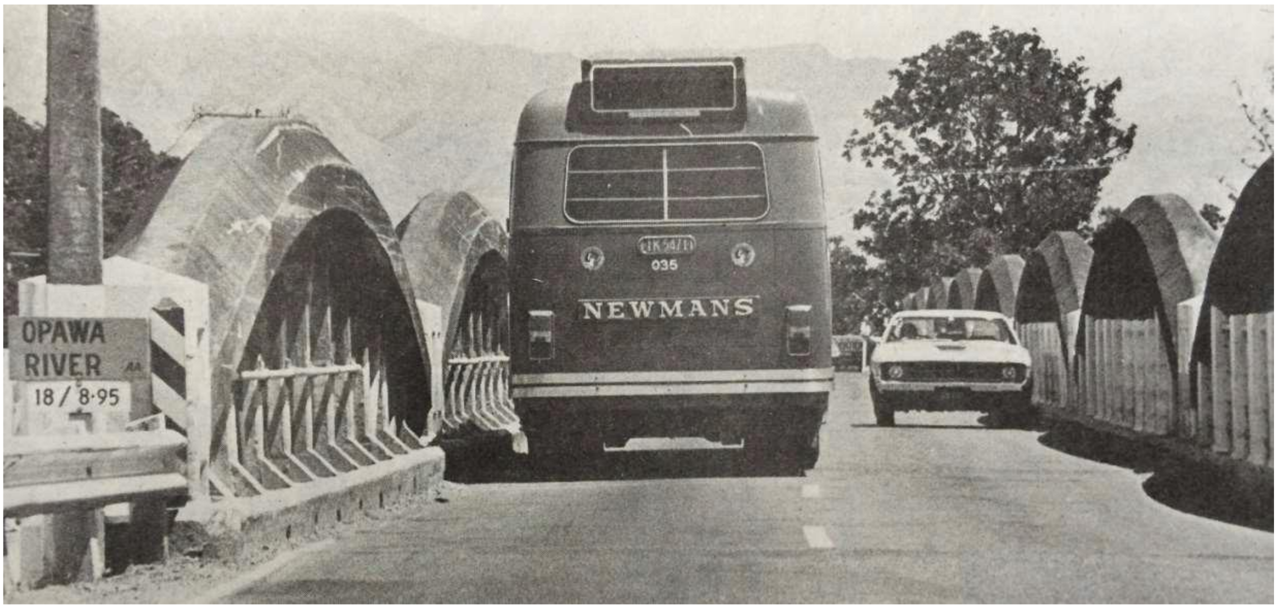
[Figure 36] Opawa Bridge under construction ca. 1915. Photographer unknown. Source: E. M. Hadfield, granddaughter of William Fryer Jr. who was a labourer on the site.

[Figure 37] Opawa Bridge under construction ca. 1915. Photographer unknown. Source: E. M. Hadfield, granddaughter of William Fryer Jr. who was a labourer on the site.

[Figure 38] Opawa Bridge from the north, c.1920. Photographed by Sydney Charles Smith. Source: ATL Ref. 1 2-045797-G

The Problem

Once constructed, the Opawa Bridge became a critical feature of the country's primary road, later designated as State Highway 1. The rapid increase in traffic volumes, and the ever-expanding size of vehicles mean that, by the late 20th century, the narrowness of the bridge deck was becoming problematic (Figure 39). During the 1980s, the Ministry of Works and Development (formerly the PWD) planned to convert the Opawa Bridge into a single-lane bridge by constructing an additional bridge downstream; but these plans were never advanced [8]. In the meantime, the bridge was inevitably being damaged by vehicles hugging the left hand side of the traffic lane to avoid oncoming vehicles (Figure 40).



[Figure 39] Opawa Bridge from the north, c.1980s., published in the Marlborough Express at the time a second bridge was proposed. Source: Trilford, D. (2015) Archaeological Assessment for the Ōpaoa Bridge Upgrade. Unpublished

In 2004, seismic linkages were installed to help prevent spans from slipping off their respective bearings due to excessive ground shaking [9]. However, ongoing concerns about the bridge's seismic vulnerability, along with the narrowness of the deck and the developing range of issues relating to the condition of the concrete (Figure 41 to Figure 44) [10], prompted a return to discussions about a second bridge. Funding for the bridge replacement project was announced in 2016.

[Figure 40] Mechanical damage to the Opawa Bridge resulting from vehicle scraping and impact.

Left: [Figure 41] Typical example of cracking on the Opawa Bridge prior to restoration works.
Right: [Figure 42] Spalling concrete on the Opawa Bridge prior to restoration works.

Left: [Figure 43] Delamination of surface render on Opawa Bridge prior to restoration.
Right: [Figure 44] Biological growth on the Opawa Bridge typical of shaded and damp areas prior to restoration.

At the outset of the project, it was agreed that the historic Opawa Bridge would not be demolished, but would be retained as an active travel (walking and cycling) link, and as a community facility for outdoor activities – simultaneously ensuring that the historic bridge continued to have a useful purpose and reducing the cost of the new bridge which would not need to incorporate active travel.

Unlike the Rakaia Gorge No.1 Bridge, I was commissioned to prepare a Conservation Management Plan for the Opawa Bridge in parallel with concept design for the new bridge early in the project. The Transport Agency, and the design team, recognised that it was necessary to understand not only the history of the bridge, but to also understand its contextual values and how these might be impacted by a new bridge, and the optimal way to execute repairs to existing fabric and manage future maintenance in accordance with best practice heritage conservation.

The Conservation Management Plan also provided a platform from which to engage with HNZPT, Marlborough District Council, and other stakeholders.

The Outcome

All existing telecom services hanging off the historic bridge were removed and transferred to new ducting in the new bridge. Once the new bridge was in operation, and the historic bridge was de-trafficked, a programme of restoration works based on the policies and recommendations of the Conservation Management Plan commenced. The intention was not to make the bridge look new; but, rather, to address or arrest deterioration.

First, the bridge was cleaned using a super-heated water (steam) cleaning system, ThermaTech. This system was chosen because it reaches deeper into porous substrates than other water-based or chemical methods, but is relatively gentle and does not abrade the material surface or force too much moisture into the fabric. Specialist operators from Auckland were brought to Blenheim for the project, and additional equipment was imported from the UK to cope with the scale of the work (Figure 45 and Figure 47). The use of mobile work platforms ensured that all parts of the bridge, above and below deck, were accessed for cleaning.

Drainage outlets were cleared as part of the cleaning and this, along with the reinstatement of open joints on the bridge deck (incorrectly sealed over in the past) was an important part of addressing drainage issues that had arisen on the deck surface.

Repairs to the concrete were made where there was evidence of corroding reinforcing by exposing the steel, treating it, and refinishing with repair mortar that was compatible with the chemistry and strength of the historic concrete. Based on the conservation principle of minimum intervention, a deliberate decision was made not to carry out cosmetic repair of gouges that had been caused by vehicle impact or delamination of historic finish coats where there was no evidence of corrosion. A biocide treatment developed specifically for historic structures in New Zealand was applied to the complete structure to retard the growth of any mould in the future, with a compatible anti-graffiti coating applied to all accessible areas. The metal railings on both sides of the bridge were repainted.

[Figure 45] Cleaning the Opawa Bridge with the Thermatech system.

Left: [Figure 46] Cleaning the Opawa Bridge with the Thermatech system.
Right: [Figure 47] Cleaning the Opawa Bridge with the Thermatech system.

One of the more challenging aspects of the project was how to integrate lighting and power supply. The Conservation Management Plan clearly stipulated that new penetrations into the bridge fabric were to be avoided. As a result, the design team had to investigate opportunities for attaching lighting and electrical infrastructure that would not permanently fix to the old bridge structure, with some limited exceptions. A custom handrail arrangement using bespoke semi-permanent bolted brackets was clamped to the existing bridge railings. This allowed for the provision of a proprietary handrail lighting system that illuminated the old bridge deck, whilst containing the extra low voltage cables within. Modified window façade luminaires were utilised, with a blade of blue light cutting through the darker area, creating visual interest. For feature lighting, a pair of spot projectors to light each truss were offset from the bridge on custom-built platforms, semi-permanently strapped to the outside of the bridge through the bridge's original drainage slots. Community events, such as markets, are catered for with power from weatherproof electrical sockets installed on trunking along one side of the bridge. Tie down points for temporary shelters were also installed on the bridge deck for use during events.

At the approaches to the bridge, the timber railings were reconstructed to the details provided in the original drawings. A significant pou whenua was commissioned as part of the project, and stands strikingly at the northern end of the bridge - the gateway to Blenheim - in a specially-constructed paved courtyard. The courtyard includes interpretation panels designed by Janet Bathgate: one developed with mana whenua, addressing the pre-European settlement in New Zealand and the Marlborough area; and one telling the story of the bridge construction, based on the historic narrative provided in the Conservation Management Plan. exploring mana whenua connections. The second panel tells of the history of the heritage bridge from its construction 100 years before through to the present day. The panels are printed on aluminium sheets protected by special sealants and anti-graffiti coating and mounted on concrete walls in the courtyard along with complementary seating allowing people to sit, read, and reflect on the stories ([Figure 48 and [Figure 49). A pile from the previous bridge, recovered during excavations for the new bridge and assessed by archaeologists, was positioned beside the panels, with an identification plaque.

[Figure 48] One of the interpretation panels placed at the north end of the bridge, designed by Janet Bathgate. Source: NZTA

[Figure 49] The rest area at the north end of the Opawa Bridge at completion, showing the location of interpretation panels and the historic bridge pile extracted during the project. Source: NZTA

[Figure 50] The Opawa Bridge at completion. Source: NZTA

[Figure 51] The Opawa Bridge (left) and the Ōpaoa Bridge (right) at completion. Source: NZTA

[Figure 52] The Opawa Bridge with lighting installed at completion. Source: NZTA

CONCLUSIONS

The Rakaia Gorge No.1 Bridge Strengthening and Deck Replacement project and the restoration of the existing Opawa Bridge as part of the wider bridge replacement project both had nationally significant heritage structures at their heart. They presented very different challenges, not just because the bridges themselves were very different structures, but because the operational outcomes being sought were also very different. What both projects demonstrate, however, is the importance of understanding a structure's heritage values, and how it should be treated in accordance with those values, before planning any changes to it. The best way to ensure this is to have a Conservation Management Plan in place.

ACKNOWLEDGEMENTS

I would like to acknowledge all of my colleagues at WSP who were involved in the Rakaia Gorge No.1 Bridge Strengthening and Deck Replacement and the Opawa Bridge Replacement projects.

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[1] Jones, G. M. (1994) 'Rakaia Gorge Bridge – The Truss That Isn't' in Proceedings of the 1st Australasian Engineering Heritage Conference. Barton, ACT: Institution of Engineers Australia, pp51-59

[2] The territories of Selwyn and Ashburton Counties were divided by the Rakaia River.

[3] Ashburton Guardian, 25 January 1912.

[4] There are reports relating to repairs to the bridge deck in 1906, and reference to repairs being required in 1909.

[5] The bridge is a pre-1900 structure and therefore recognised as an archaeological site under the Heritage New Zealand Pouhere Taonga Act; but it is not considered to be a building and therefore is not exempt from the requirement to obtain an authority to modify in the same way that a building is exempt.

[6] The Pratt truss is one of the most common type of truss used in bridge construction. It is typically trapezoidal with diagonal members forming a V shape towards the centre, and often the members in the central bay are crossed as can be seen at the Opawa Bridge.

[7] Dinan, A. (2014) SH1 Opawa Bridge – RP 18/9.015: Management Plan prepared by Opus International Consultants Ltd for the New Zealand Transport Agency

[8] Marlborough Express, December 29 of c.1980.

[9] Dinan, A. (2014) SH1 Opawa Bridge – RP 18/9.015: Management Plan prepared by Opus International Consultants Ltd for the New Zealand Transport Agency

[10] The draft Conservation Plan for the Opawa Bridge (Stevens, 2016) provides a detailed condition assessment of the existing bridge. The following forms of deterioration were observed:

- cracking, pitting, spalling and delamination of concrete
- corrosion of reinforcing steel
- staining associated with environmental pollutants
- organic growth
- mechanical damage
- painting and graffiti
- animal deposits
- poorly executed patch repairs
- damage to metal railings

DUNEDIN LAW COURTS – SEISMIC STRENGTHENING AND REFURBISHMENT

J.F. Finnegan & T.J. Holden
Aurecon New Zealand Limited, Wellington

Summary: The Dunedin Law Courts is a Category 1 Heritage Building that holds an essential civil function. Following the devastating Canterbury earthquake sequence the Crown opted to seismically strengthen the building to a level well in excess of the minimum for heritage buildings.

Substantial strengthening was required for the tower, building foundations, diaphragms, masonry walls and support of the tourelle features. Each of the structural solutions was carefully engineered and located so their effects on the heritage fabric were minimised and the work was hidden from view. The end result reflects careful coordination with all design team members, including incorporation of its iconic heritage value.

Dunedin Law Courts, Seismic Strengthening, Heritage Building, Structural Engineering

PROJECT OBJECTIVES

The Dunedin Law Court, built in 1902, was designed prior to the establishment of any formal New Zealand seismic design provisions. (typically, only buildings built in Wellington before 1935 considered any form of seismic design). Since then there have been considerable advances in the field of earthquake engineering and these new codified requirements will impact on any proposed additions or major alterations which constitute a “change of use”.

The Local Authorities require the buildings under these classifications to be brought up to “as near as reasonably practical” to current standards, as set out in the New Zealand Building Code (2000). Per Dunedin City Council’s current Earthquake-prone Buildings Policy, the council will accept 67%NBS, or better, of the current design code for a new building built on the site as being “reasonably practicable”.

The building has been considered as an Importance Level 3 (IL3) building as described in NZS1170.0, and as required by the Ministry of Justice, due to its heritage status.

Structural design to support the project outcomes

The structural strengthening design of the Building supports the Client’s project outcomes in a number of ways.

- Improvement of the seismic capacity of the existing structure to at least 70%NBS IL3
- Strengthening works concealed under replaced architectural finishes
- The new structure to not change the general layout or appearance of the existing building, particularly the exterior of the building and to areas deemed to have significant heritage value

Scope of design

- The specific works the Ministry required to be undertaken to the building included the following:
- Seismic strengthening of the building
- Allowance for liquefaction and lateral spreading
- Secure parapets and ornamentation
- Provide roof and ceiling diaphragms and to provide diaphragm connections
- Seismic strengthening of the tower
- Provide additional structural elements to the building to carry the calculated loads in discrete areas of the building
- Strengthening of existing masonry shear walls
- Tying the exterior leaf of masonry to the interior leaf
- Courtroom floor strengthening
- Coordinate with the design team to minimise disruption to the existing building fabric and make good to all disturbed surfaces.

BUILDING DESCRIPTION

Building description

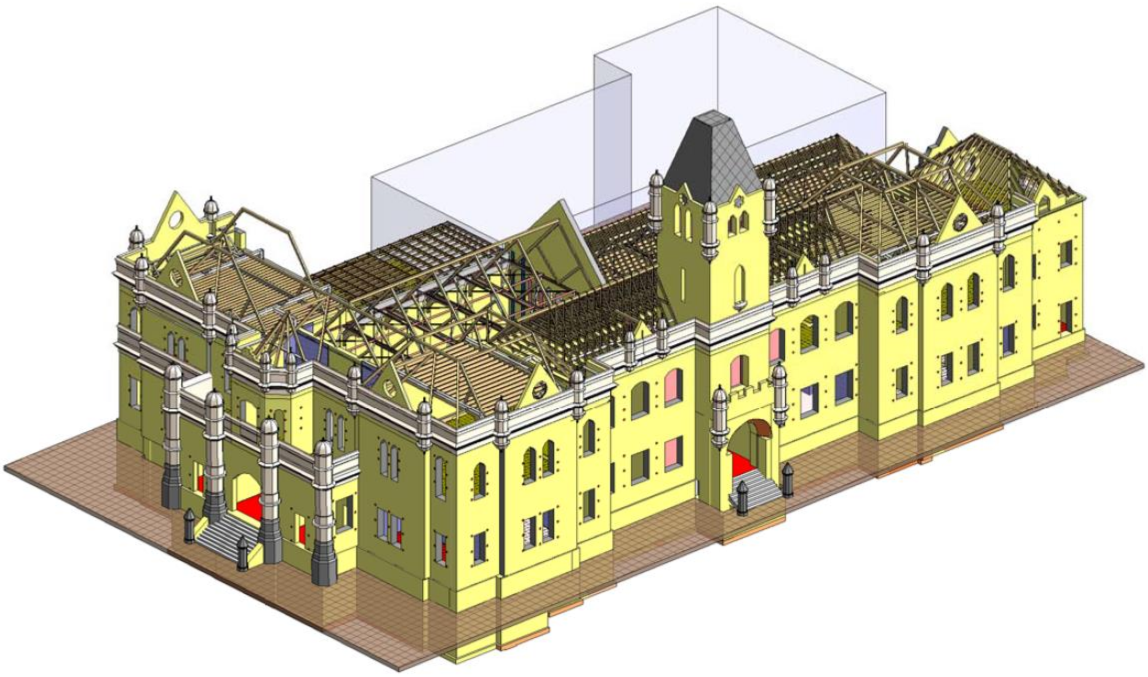
Dunedin Law Courts is an existing 2-3 storey building situated at 1 Stuart Street, Dunedin. The building was constructed in 1902, is fairly regular in plan, with dimensions of approximately 32m x 56m, and stands at a height of about 9 metres to the First-Floor ceiling. The Ground Floor contains lobbies, security areas, offices, restrooms, and court rooms with two-floor high stud ceilings. The First-Floor houses judges' chambers, offices, a library, breakroom, and restrooms.

Wall construction materials include unreinforced masonry (URM) brick for interior walls, 2-4 leaves in thickness. Exterior walls primarily consist of an interior layer of unreinforced brick, an air cavity, with a combination of unreinforced Breccia and Oamaru limestone for the exterior layer. The exterior boasts several large limestone ornamentations hanging proud of the face of the building at the First-Floor level, at the bottom of roof trusses, as well as, at the top of some of the roof ridges. Roofs are constructed of timber trusses with timber sarking and clad with slate tiles. Foundations are typically unreinforced concrete strip footings below the unreinforced block walls and isolated unreinforced brick piers which support the ground floor timber framing.

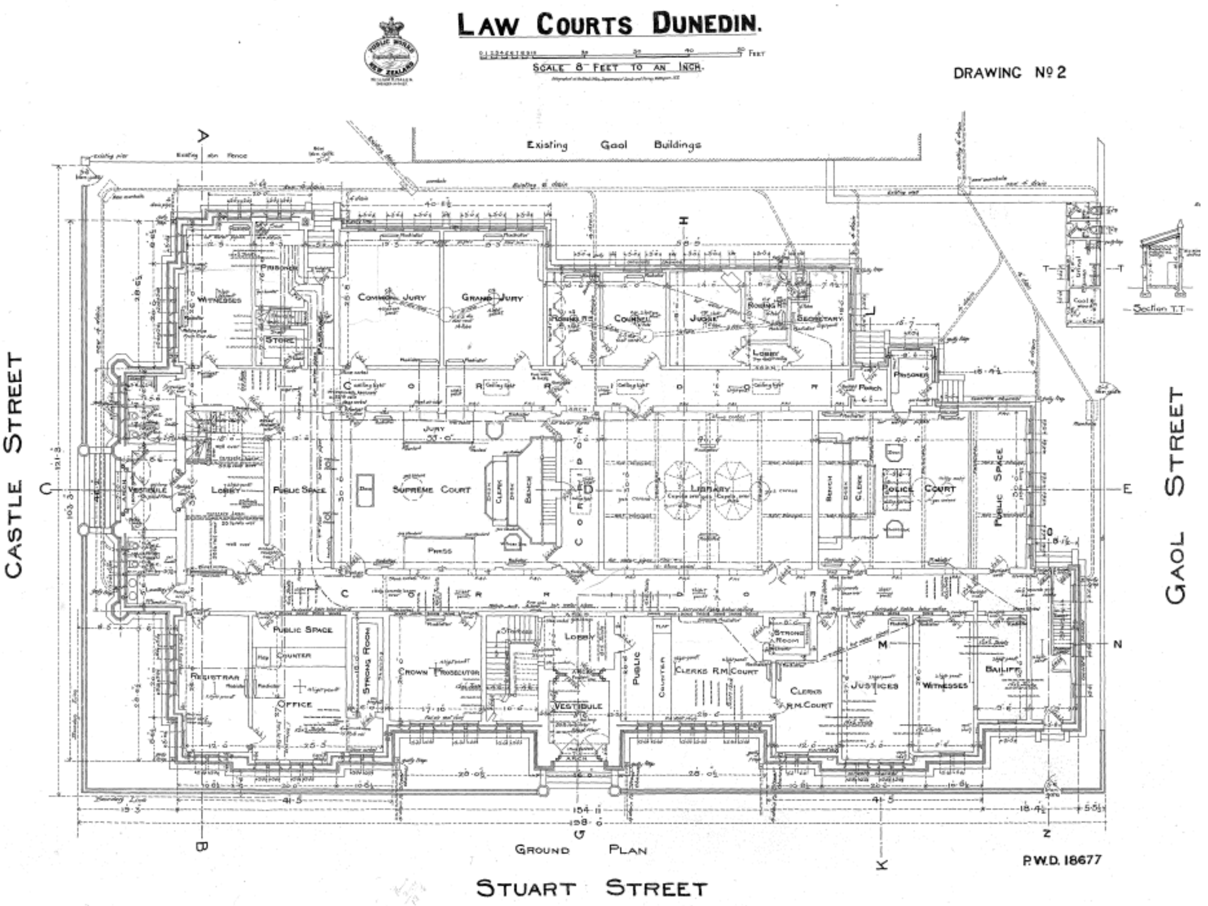
A four-storey URM brick and Oamaru stone tower integrated within the main structure is located at the Northern end of the building.

The building is classified as a Category 1 heritage structure.

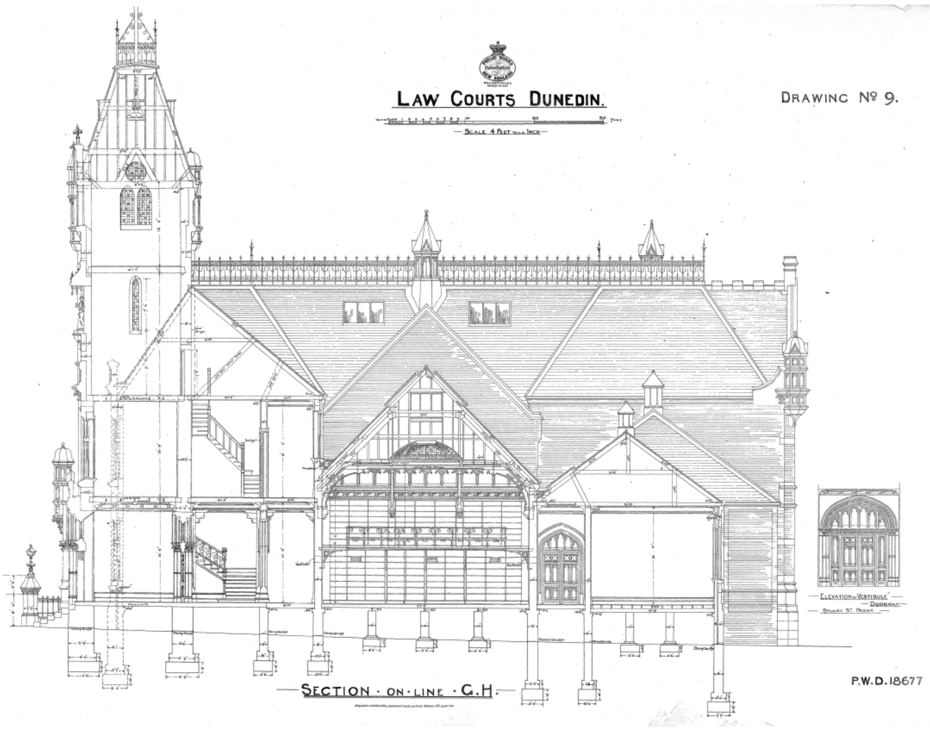
[Figure 1] Photo of northern exterior of Dunedin Law Court Building.



[Figure 2] 3D REVIT model showing the general structural form of the Dunedin Law Courts.



[Figure 3] Original drawings showing plan.



[Figure 4] Original drawing showing cross section.

Soil conditions

Soil Profile

The generalised stratigraphy beneath the site comprises three varieties of fill underlain by alluvial and estuarine soils that overlie completely weathered bedrock of the Dunedin Volcanic Group.

The soil profile at the site is represented below.

Table 1 – Soil profile

Layer No.	Description	Depth to Top of layer (m)	Layer Thickness (m)
1	FILL Stiff clayey SILT with rare fine gravel and sand.	0	Up to 2.0
2	BOULDER FILL Fragmented basalt with silt observed in SPTs. Driller reports basalt boulders. Probably dense.	0 - 2	0 – 1.8
3	RECLAMATION FILL Loose to medium dense, variable sand-dominated soils including SAND fill (BH2), silty SAND, silty GRAVEL with rare sand & gravel.	0.2 – 3.8	1.8 – 6.7
4	HARBOUR MUD Soft to stiff SILT, dilatant	5.6 – 6.9	0.6 – 4.7
5	ALLUVIAL SILT Stiff to hard inter-bedded clayey SILT, sandy SILT and SILT & SILT with rare sand-gravel (also includes occasional estuarine (harbour mud) silt lenses. Refusal on “boulder” at 15m (possible bedrock)	6.8 – 10.5	Unproven but estimated as approx. 10.0m

Water levels within the boreholes and piezometer varied from 1.7 to 2.2m below ground level.

Liquefaction

A liquefaction assessment was carried out. The results of the liquefaction analyses indicated:

- There is no liquefaction predicted under the SLS seismic event (1/25)
- There is predicted to be liquefaction under the 1/1,000 and 1/2,500 ULS seismic events within the harbour muds under the entire site
- Soft harbour muds around 5 to 7m depth in BH1401-1402 are considered to be non-liquefiable under the 1/1,000 and 1/2,500 ULS seismic events (see Section 5.4.3)
- There is predicted to be liquefaction under the 1/1,000 and 1/2,500 ULS seismic events within the reclamation fill in the eastern parts the site only (BH1 and BH-1403), where this stratum is looser. The reclamation fill in the other investigated parts of the site was generally too dense to liquefy

Lateral Spread

The western end is underlain by dense boulder fill and has a reasonable thickness of non-liquefiable crust. The eastern end is underlain by shallow liquefiable soils. Hence there is a potential for lateral movement at one end of the site and not so much at the other end.

The expected lateral spread is about 10mm in a 1 in 1000-year event and 20mm-30mm in a 1 in 2500-year event. There is not expected to be any lateral movement in an SLS event. Advice on these figures allowed for a potential spread from down to half or up to twice these figures.

STRUCTURAL DESIGN

The structural designs utilised a combination of current New Zealand design Standards and new draft assessment guidelines that were available in 2015. Elements of key concern and their strengthening methodologies are described below.

Foundations

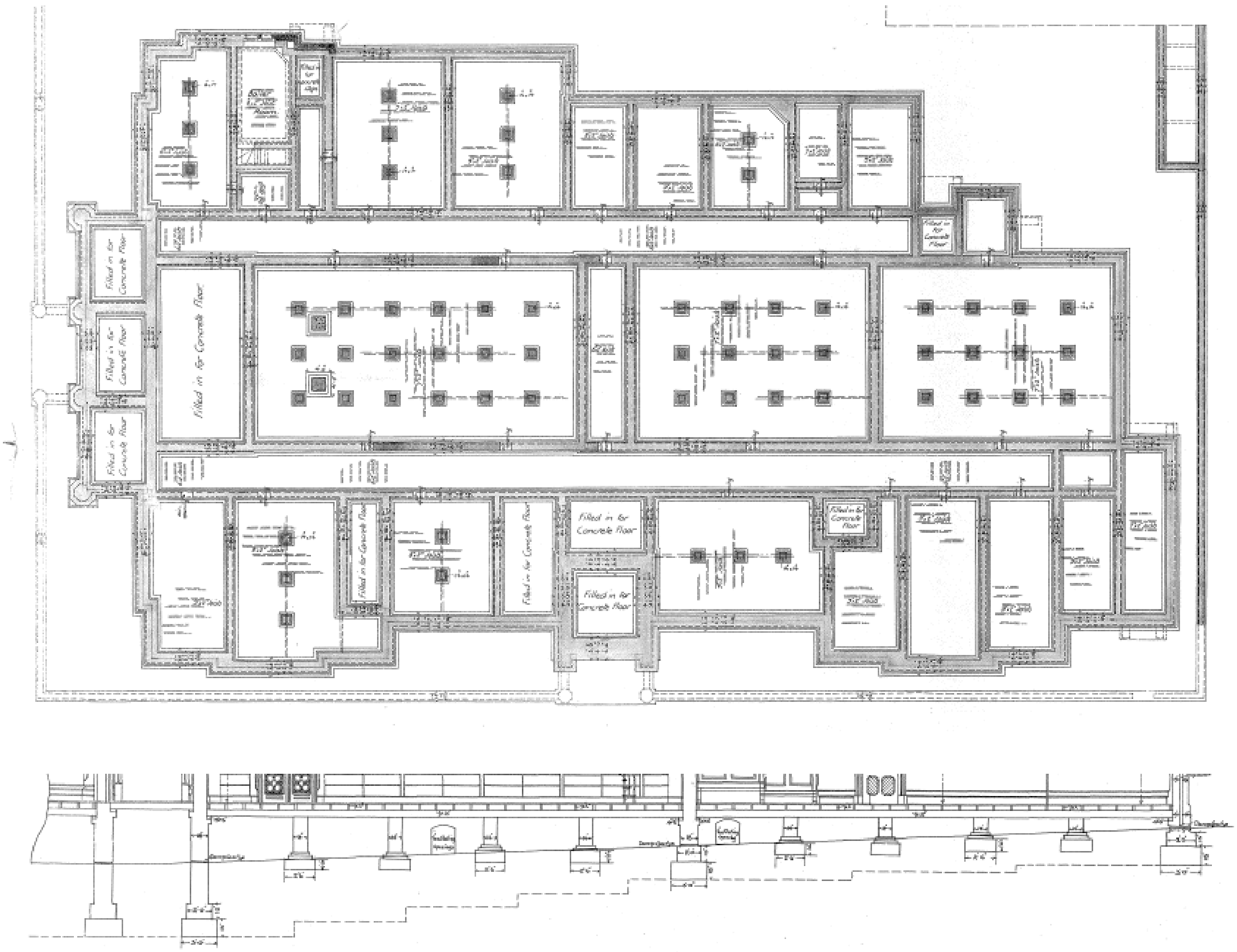
A detailed geotechnical investigation of the site was completed by GeoSolve in June 2014, confirming the seismic subsoil category to be Class C (Shallow Soil). Based on the findings of this report, the calculated free-field settlement at the ULS event (with a return period of 2500 years) is 150mm-200mm at the east end of the building. The worst-case Liquefaction Severity Numbers occur at the east end of the building, and have “severe, high risk of substantial damage to the site and/or dwelling”. This level of severity also occurs at the 1:1000-year event at this site location.

The report also analysed the likely lateral spreading over the length of the structure, the strain of which is 20-30mm at the 1:2500-year event, with advice to double this as sensitivity options. As the foundations are unreinforced, they have limited ability to undergo the relative and varying applied deformations generated by the lateral spreading. If the foundations are inadequate, the walls will have no ability to resist the tension loads in the event of lateral spreading and settlement, as the later will cause the mortar bed to be in tension, rendering it inadequate for shear resistance in-plane.

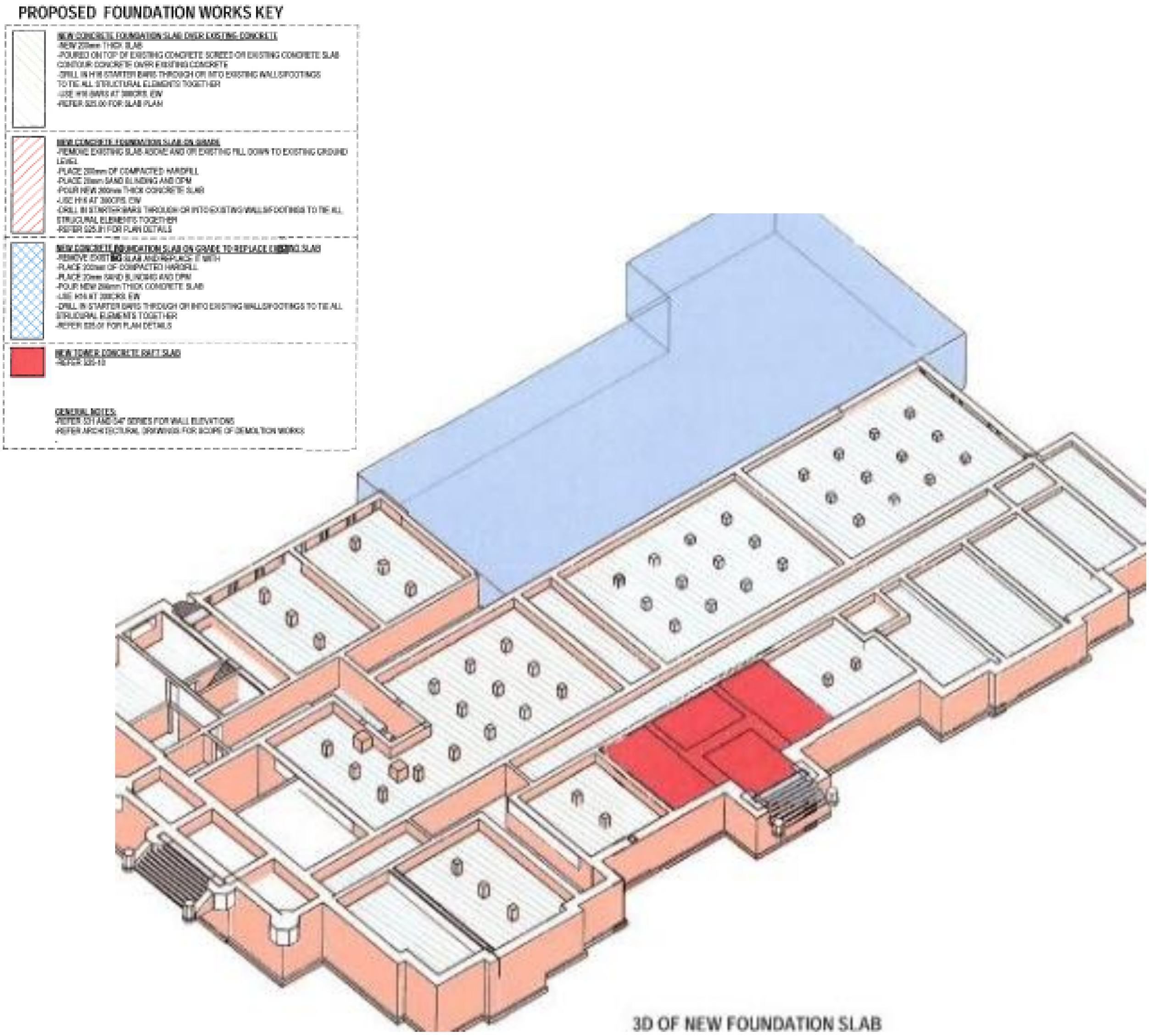
In the worst case, if the foundations are pulled askew by the settlement and lateral spreading, then the gravity support of the structure would be compromised, and a partial or full collapse could occur.

A 200mm thick reinforced concrete slab was located at the ground level to effectively tie the walls together at foundation level.

The soils under the foundations of the north tower were also discovered to not be stiff enough to prevent settlement under the ULS tower loads. The settlement calculated by Geosolve under the tower loads would cause the tower to tilt past reasonable limits, given the seating of the floors and roof on the tower walls. To remediate this effect, the soil beneath the tower was stiffened with jet grouted, unreinforced piles, extending down approximately 10 metres.



[Figure 5] Original drawings showing plan and cross section views of the existing foundations.



[Figure 6] Photos showing existing URM wall and timber bearer pier supports, and new reinforced concrete link slab.

Walls

The in-plane and out-of-plane strength of the unreinforced block walls was calculated based on accurate in-situ material property values obtained by materials testing agency OPUS. The strengths and allowable deformations were compared to the demands on the walls, in order to verify which walls require strengthening and how much strengthening was required.

Where required, strengthening of walls in-plane included fibre-reinforced polymer (FRP) layers. The failure mode of the walls (either diagonal tension cracking, toe crushing, bed joint failure, or rocking) determined the performance requirements of the FRP. The exterior wall layers of brick and Breccia were not adequately tied together, and the floors and trusses frame into the interior skin only. New ties were required between the two in order to effectively utilise the strength of both layers, particularly for out-of-plane loading. It has been determined that the two leafs do not need to be tied together in-plane. The outermost breccia layer was capable of supporting the lateral loads from the acceleration of its own weight in-plane. The interior layer of brick supports the lateral loads in plane caused by the acceleration of the floors, roof, and the brick wall itself. This brick layer did require some strengthening to achieve this.

The URM walls out-of-plane have been assessed using the latest proposed assessment procedure for the updated NZSEE building assessment guidelines.

The URM walls in-plane were assessed using the "Assessment and Improvement of Unreinforced Masonry Buildings for Earthquake Resistance" by the University of Auckland, dated December 2011.

[Figure 7] Photos of existing URM interior wall core samples, illustrating their solid construction with no internal cavity.

Diaphragms

The Ground and First Floor diaphragms were not adequately connected to the block walls with only a gravity connection present. This interface required a new connection transferring diaphragm shear forces from the top of the floor framing to the block walls.

The Ground and First Floor timber diaphragms were overlain with new plywood sheets to tie the structural elements together, as well as, provide a reliable load path for seismic actions. They were strengthened to 100% of the seismic forces.

The out-of-plane forces from the URM walls, transferred to the diaphragms, have been calculated using the minimum of the wall destabilisation load or the parts and portions load. If the wall is destabilised before the parts and portions load is reached, then this is the highest load imparted on the wall out-of-plane. If the parts and portions load is reached before the wall destabilises, then the highest load the wall will see is the parts and portions load.

It is understood that the timber framed Ground Floor was susceptible to vertical movement and vibrations particularly in the main court rooms. Further investigation revealed several areas where the floor boards and gravity framing were not connected due to settlement and warping. The floor system was made true and level, and the subfloor was adequately connected to the framing, which resulted in a stiffer floor system, not suffering from vibration and creaking. It is also noted that the timber bearers at the Ground Floor were not tied to the isolated URM piers. The introduction of a plywood diaphragm helps restrain the bearers against the risk of losing their seating.

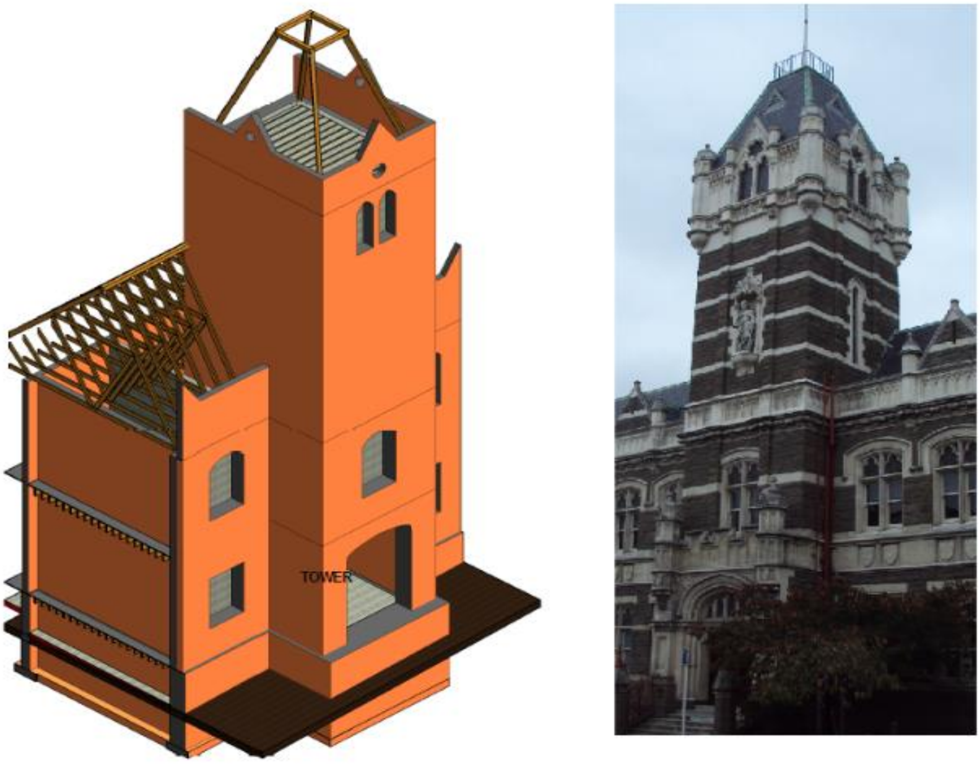
The existing roof diaphragm above the low and high courts was assessed to be inadequate to resist the seismic lateral loads generated from the wall mass and services. A new steel bracing diaphragm was installed for this purpose. Elsewhere a plywood diaphragm was installed to the underside of the roof trusses similar to that proposed at the Ground and First Floors.

[Figure 8] Photo of existing timber bearer on URM supporting pier. No tie or direct fixing is evident.

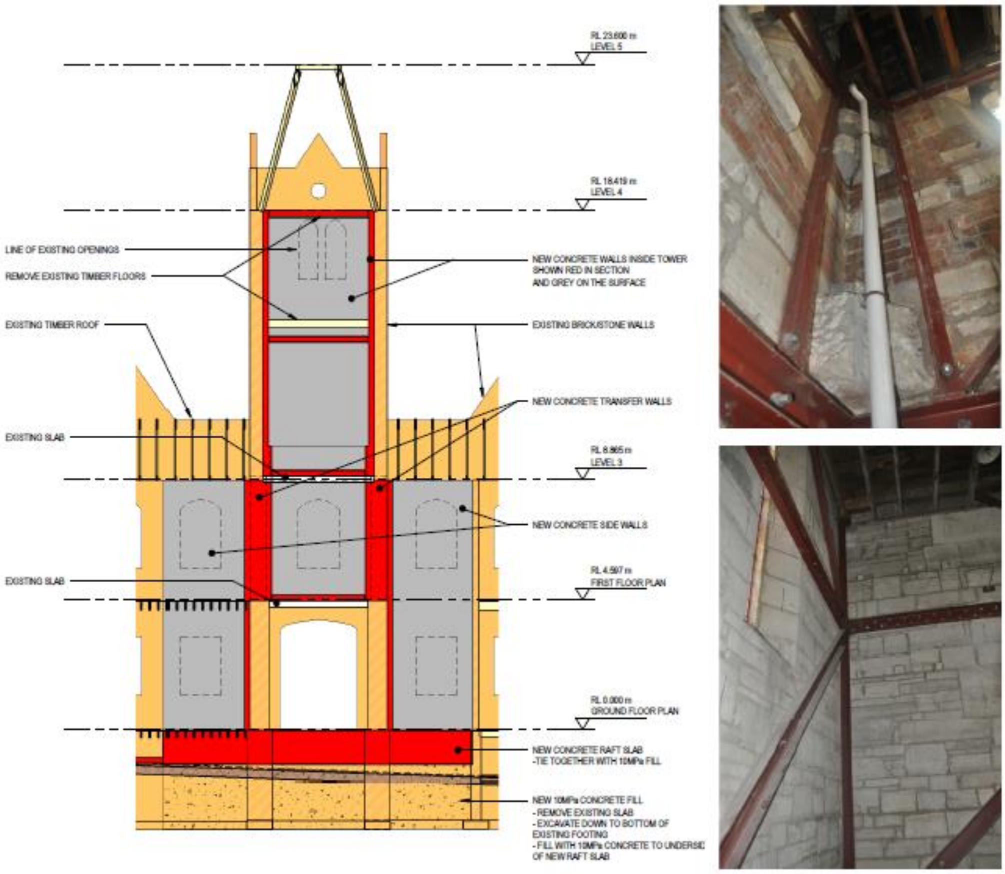
The main tower

The tower at the northern end of the building has been assessed as being a high-risk element and prone to collapse in a seismic event. The tower had previously been strengthened using structural steel bracing members epoxy bolted to the inside walls. This bracing was considered to be inadequate for the seismic demands required to be resisted as part of the proposed strengthen works, and was removed, and the tower walls were strengthened with reinforced concrete to 100% seismic loads. The new walls were both internal and external to the masonry walls, constructed both as shotcrete and as poured concrete. A large reinforced concrete raft slab was introduced to carry overturning and bending loads at the foundation level.

Geotechnical investigation determined that the soil bearing pressure caused by overturning of the tower would have caused excessive vertical settlement, which in turn causing unallowable separation of the gravity structure from the tower wall. Ground improvements below the tower were proposed by GeoSolve and were designed and specified by GeoSolve. The proposed scheme involved unreinforced jet piles, extending to a layer of soil with good bearing qualities, increasing the available bearing capacity under the tower.



[Figure 9] 3D REVIT and photo illustration of tower structure.



[Figure 10] Reinforced concrete internal skin strengthening of tower, with photos of the existing seismic steel bracing to be replaced.

Ornamentation and parapets

The connection of the ornamentation to the outside face of the building was unknown. New fixings were designed to reliably anchor the heavy decorations to the exterior walls in the event of a major earthquake. This work involved drilling into the existing ornaments and epoxying steel rods to restrain and tie these back to the structure.

The existing parapets were braced back to the roof sub structure to provide out-of-plane loading resistance with steel struts and walers.

The roof gable ends had been previously strengthened, and the strengthening was determined to be adequate.

All ornamentation assessment and ornamentation strengthening has been designed for 100% seismic loads.

[Figure 11] Photo showing typical URM and Oamaru stone parapets and ornaments which required additional seismic restraint.

SUMMARY

This heritage project breathes significant life into the Dunedin Law Courts, originally built between 1900-1902. The building is one of the older assets of the Ministry and, as a result, it presented a number of compromises for modern use. The client, design and construction team collaborated strongly to research the building fabric, coordinate all of the engineering and architectural requirements and work closely together to affect the seismic strengthening and refurbishment. The result is a significant refurbishment and structural strengthening of this formerly underutilised heritage building to significantly raise the seismic strength, retain the heritage aspects and to optimise its use as a court and administration function.

[Figure 12] Photo showing original Dunedin Law Courts.

REFERENCES

Geosolve Geotechnical Report 22 December 2014

WELLINGTON TOWN HALL – MAINTAINING HERITAGE IN A COMPLEX SEISMIC RETROFIT

G McFetridge, E Norton

Naylor Love Wellington

Summary: This paper outlines some of the major challenges that contractors face in the procurement and delivery stages of heritage refurbishments and presents some case studies for the design of the methodology and associated temporary works required.

This paper focuses on the protection of heritage and seismic strengthening of Wellington Town Hall. The strengthening of this building involves introducing a new base isolated foundation system beneath the existing unreinforced masonry (URMs). Construction of this new structure requires unique temporary works solutions to maintain lateral and gravity support to the existing building during the works.

The Town Hall will also undergo an internal refurbishment that retains much of the existing fabric with highly valued heritage features. The Wellington Town Hall has been described by WCC as the most challenging project undertaken in Wellington over the last 15 years and is potentially the most complex within New Zealand currently.

1.0 OVERVIEW

The Wellington Town Hall is a large unreinforced masonry (URM) building constructed between 1901 and 1904. The Town Hall is located on Civic Square in central Wellington. The building features a large auditorium as well as the offices of the Mayor and a Debating Chamber for the City Council. Having been identified as an earthquake-prone building, the Town Hall is currently undergoing seismic strengthening.

[Figure 1] Wellington Town Hall in 1904, just prior to opening

1.1 HISTORY OF THE TOWN HALL

The Wellington Town Hall was opened in 1904 and served as a council administration space as well as a venue for major public events. The foundation stone for the Town Hall was laid in 1901, by the Duke of Cornwall and York, while he and the Duchess of Cornwall and York were visiting New Zealand. Following the death of the King, Edward VII, in 1910, the Duke and Duchess would later be known as George V and Queen Mary.

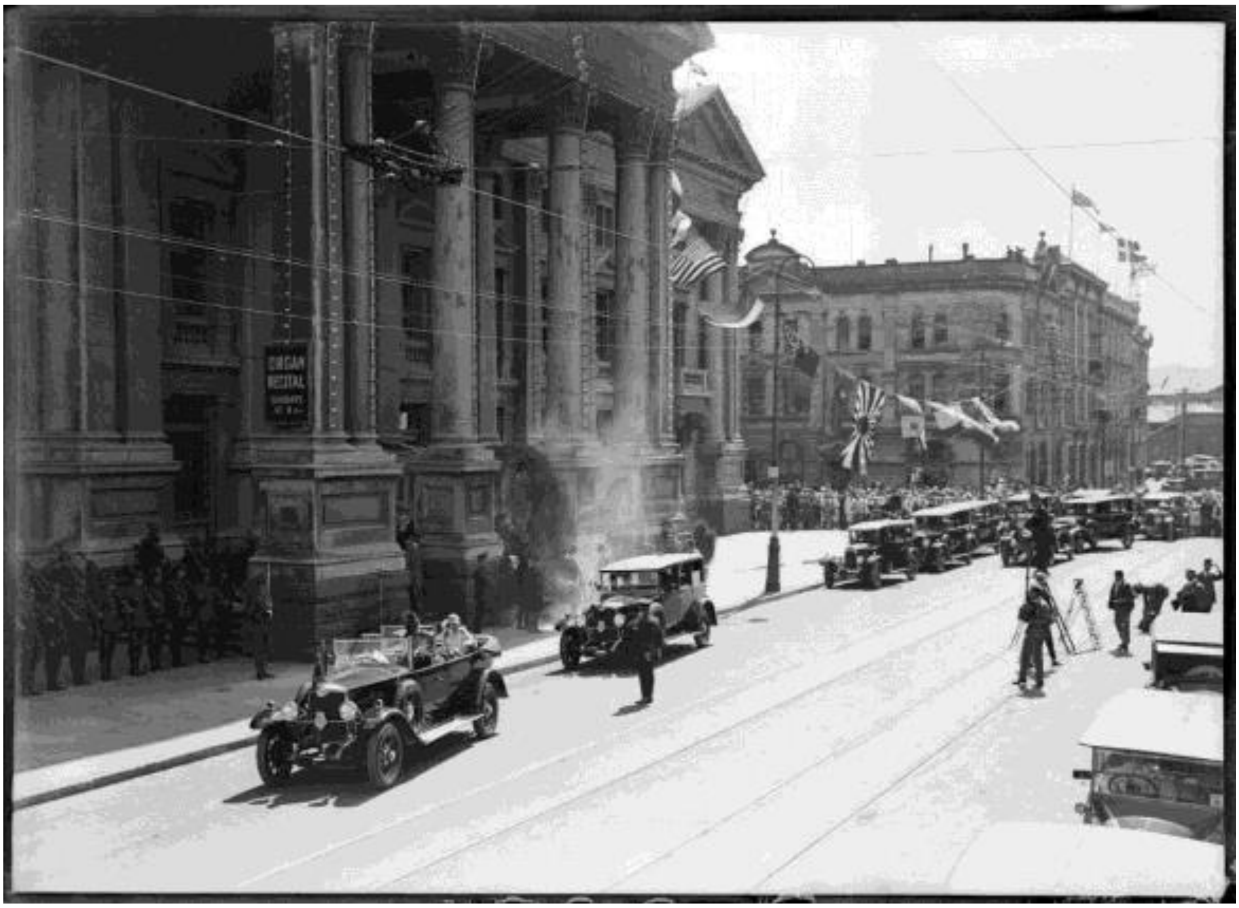
The Wellington Town Hall was further visited by the Duke and Duchess of York in 1927. Following abdication of the throne by his brother, Edward VIII, in 1936, the Duke and Duchess would later be known as George VI and Queen Elizabeth.

In 1931, a devastating magnitude 7.8 earthquake struck Hawke's Bay, causing significant damage to the cities of Napier and Hastings. This event highlighted the risk associated with unreinforced masonry across

New Zealand. In 1934, following a review of the Town Hall's seismic capacity, the clock tower, main entrance portico, high parapets and other external ornamentation were dismantled.

In 1942, damage to the Town Hall occurred from two large earthquakes which struck the nearby Wairarapa Region. In addition to repairs to the cracks in the URM walls, concrete buttressing and recessed vertical concrete bandings were introduced to the auditorium and exterior walls. In the late 1940s and early 1950s, the Municipal Office Building (MOB) was built on the western boundary of the Town Hall with the two buildings integrally linked at the southwest corner.

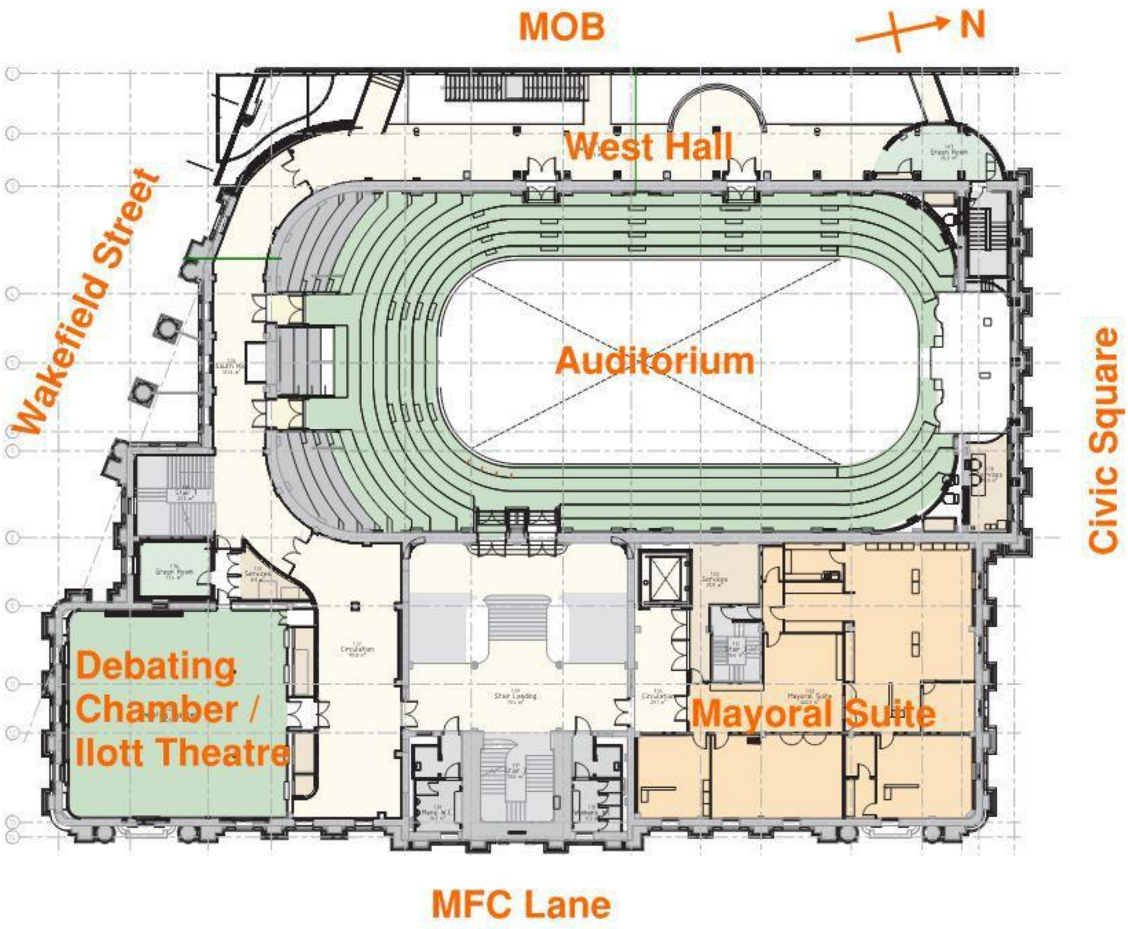
The Wellington Town Hall saw the first visit by a reigning monarch in 1954. A civic reception was held for Queen Elizabeth II and Prince Phillip, Duke of Edinburgh at the Town Hall on the morning of the 11th of January. Further royalty visited the Town Hall when the Beatles played two consecutive concerts in June 1964. The Town Hall played host to numerous civic receptions and concerts over the years embedding itself as an integral part of Wellington society.



[Figure 2] Arrival of the Duke and Duchess of York to the Town Hall in 1927

The Town Hall underwent significant alterations and seismic strengthening in the early 1990s, with conversion of the eastern section into office space and a small theatre, and construction of a new concrete frame structure along the western elevation. The main auditorium was largely untouched during these works.

Detailed Seismic Assessments completed between 2009 and 2013 identified the building as "earthquake prone" meaning that it had less than one-third of the capacity of a new structure built in accordance with the current building standards. Wellington City Council (WCC) closed the building in 2013 and began investigating options to retrofit the building. Figure 3 shows a plan layout of the building at the start of current construction works in 2019.



[Figure 3] Plan layout of the Town Hall in 2019

1.2 SIGNIFICANT HERITAGE ITEMS

The Town Hall exhibits a prominent, neo-Classical, masonry edifice. The building is arguably the greatest design by Joshua Charlesworth, one of the pre-eminent Wellington architects around the turn of the last century.

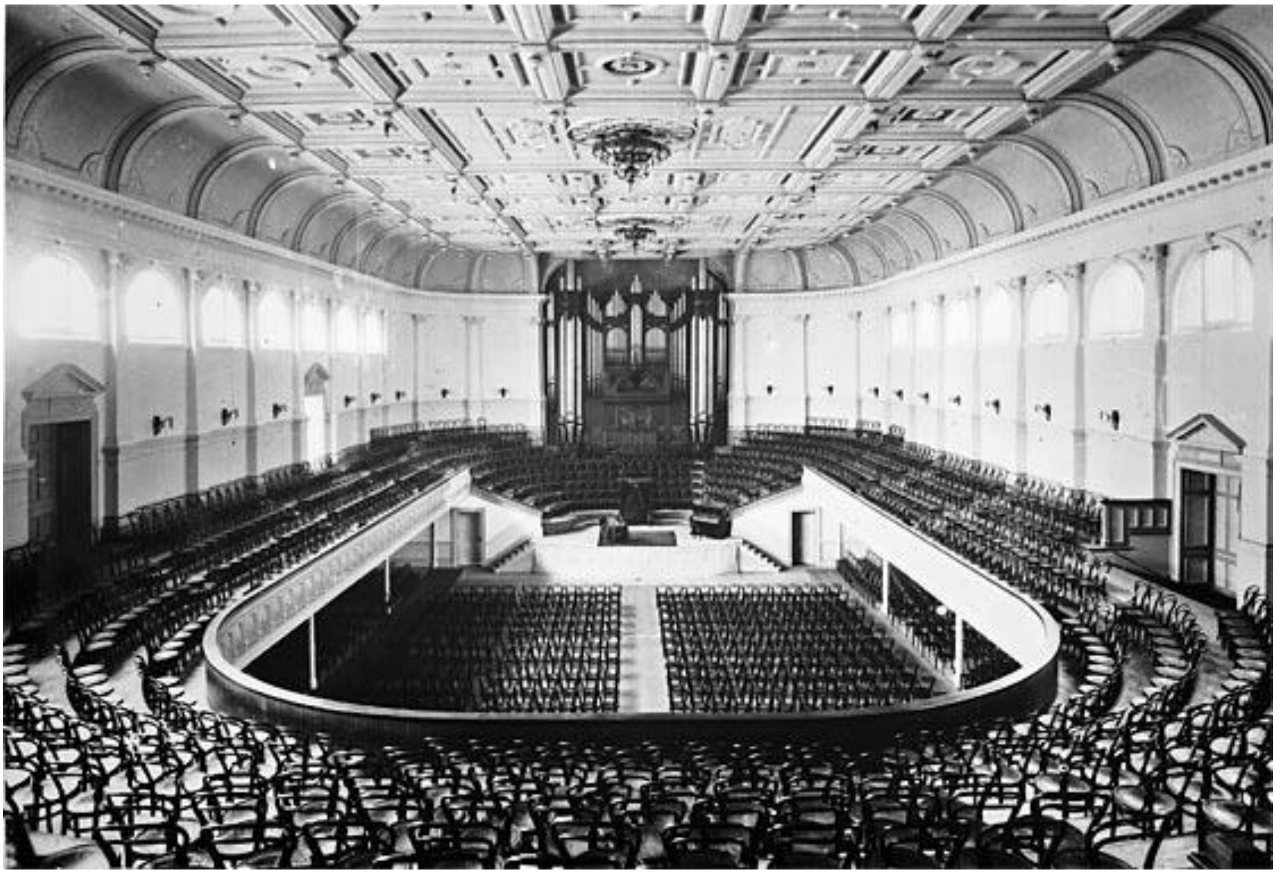
According to the heritage Architect, “Although the building has undergone a number of modifications over the years, especially to the exterior detailing, the fundamental form, layout, materiality, and civic meaning of the original design has not been unduly compromised.”

The main auditorium has been described as having world-class acoustics and was home to the New Zealand Symphony Orchestra (NZSO) until the Town Hall was closed in 2013. The auditorium also was home to the concert Organ, built in 1906, it was one of the few remaining organs in the world that remained in its original state.

The main foyer and entry to the auditorium is between two branches of elegant, bifurcated stairs. Ceilings are ‘Wunderlich’ stamped zinc throughout and are found in a variety of patterns.

The roof trusses across the major spaces are ‘engineered’ queen-post types, made from massive Oregon timbers joined by steel plates.

Heritage New Zealand had given the building a Category 1 rating, the highest possible rating in New Zealand, recognising the building's outstanding historical and cultural significance.



[Figure 4] Historic photo of auditorium with organ in background

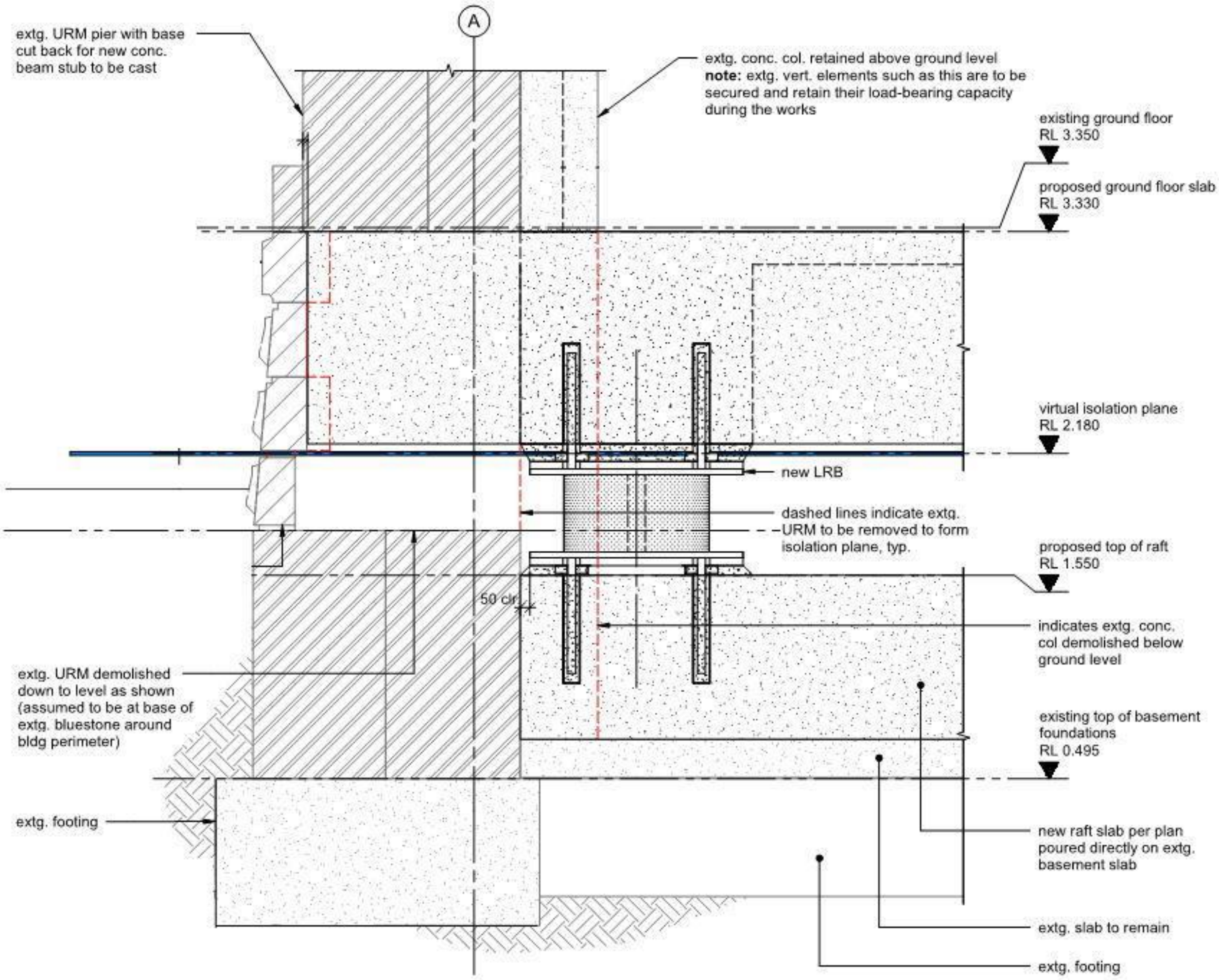
1.3 PROPOSED STRENGTHENING

The Town Hall was constructed on reclaimed land and is located less than 2km from the Wellington Fault. Detailed Seismic Assessments carried out between 2009 and 2013 classified the building as 'earthquake-prone'. The main structural weaknesses associated with the Town Hall derive primarily from the unreinforced concrete pile foundations and the brittle URM walls.

The Town Hall is founded on reclamation fill over beach deposits over alluvium with bedrock considered to be over 45m below current ground level. The seismic retrofit involves completely re-founding the building, both vertically and laterally onto a network of over 450 screw piles. The piles were screwed down into the alluvium layer, to a depth of between 8 – 15m below the existing basement level. The screw piles were also designed to accommodate liquefaction within the ground. The piles support a heavily reinforced raft slab foundation, typically 850mm thick.

Another key element of the seismic retrofit involves the introduction of a base isolated system. The base isolators can displace up to 450mm in the event of an earthquake, thereby significantly reducing the seismic forces acting on the brittle URM walls above. A cross section of the proposed retrofit is included in Figure 5 which shows the load path through the existing URM walls down to the new ground beams, through the base isolators, through the raft slab and into the screw piles where it is dissipated into the ground below.

Underneath the auditorium floor, a new basement will be dug to accommodate a high-end recording suite, storage facilities, practice rooms and dressing rooms. The seismic retrofit design also incorporates concrete overlay on selected URM walls, new concrete frames along the western elevation, strengthening of the existing roof structure as well as diaphragm strengthening ties across the existing concrete floors.



[Figure 5] Proposed foundation strengthening cross section

2.0 CONSTRUCTABILITY

Retrofitting and uplifting a complex heritage building, such as the Town Hall, is never straight-forward with the engineering and architectural designs coming together as an iterative process where key design constraints and assumptions are tested and re-evaluated. At the end of construction, the client and consultant must be confident that the building will perform as expected whilst maintaining compliance with all the relevant engineering codes, building standards, etc.

The tender drawings represent the cumulative design efforts of multiple consultants working thousands of hours to create a final building design that is in the best interest of the client and multiple stakeholders.

With this intent focus on preparing the “final” design, the construction sequencing by the consultants may not receive the full attention that it deserves. Often for seismic retrofits, there is a requirement for, sometimes significant, temporary works to maintain structural support. Access of heavy machinery into and around the building, for demolition and installation of the permanent works is also a key consideration. This is where an experienced Main Contractor can add significant value by utilising their own resources, previous experience, and connections with sub-contractors to take the building from its current state to the finalised design envisioned by the client and their consultants.

2.1 HERITAGE AT THE DESIGN STAGE

The key decisions about retention and protection of important heritage fabric are made at the design stage. The selection of the type of engineering strengthening and architectural fit out can greatly affect the scale of any disturbance to heritage items. The Contractor must understand the context in which these key design decisions are made so they can complete the construction while complying with the assumptions made in the design stage.

For the Wellington Town Hall, the following key decisions were made at the design stage to protect the building's heritage fabric.

- An emphasis on preservation of the heritage fabric on the exterior side of the building was made which restricted all the remediation works to the inside only. This prevented any seismic strengthening on the outside of the building and resulted in a ground beam design that effectively cantilevers out over the isolators to pick up the load from the external URM piers.
- The auditorium was treated with careful consideration to avoid altering the appearance or acoustics associated with the most prominent and celebrated spaces within the Town Hall. This resulted in all seismic strengthening to the Auditorium walls being completed on the exterior sides.
- Base isolation was incorporated which enables the building to experience far reduced accelerations in a seismic event, thereby decreasing the demand on URM structure. By utilizing base isolation, most of the retrofit works could be kept at the foundation level, reducing the scale of strengthening works required above the ground floor. Holmes noted that "without base isolation, any seismic strengthening intervention would have been so intrusive as to destroy any remaining heritage aspects of the building rendering the project unworkable."
- Screw piles were selected as the preferred foundation option as the piles could be installed in sections and welded together. Therefore, the screw piles would be best suited for the constrained nature and reduced head heights within the Town Hall. Furthermore, the piles are screwed into the ground which causes less disturbance than bored or driven piles and reduces the risk associated with foundation settlement in the existing structure.

2.2 SAFETY IN DESIGN

According to "The Seismic Assessment of Existing Buildings", buildings that are rated less than 33% NBS have an approx. 10 – 25 times greater risk relative to a new building and the risk to life safety is considered High. Many employers have policies in place forbidding their staff from working in earthquake prone buildings. In Wellington, typically larger companies will not rent or occupy buildings rated less than 66% NBS.

Similarly, construction companies are involved in lowering the risk associated with earthquakes on their employees. However, for seismic retrofits, we require people to work within earthquake prone buildings. Also, in some cases, the buildings need to be made weaker during the construction process so permanent works can be installed. Understanding and managing worker safety through the build process can be complex.

At the Wellington Town Hall project, this was addressed by base principles that each temporary works design had to consider:

1. Do not remove more than 25% of the lateral capacity of the building on any structural line.
2. Do not weaken the structure: provide at least the same capacity in the temporary works as has been removed.

The two principles seem to be somewhat at odds, but together they recognise that the building has some capacity and that the workfaces must be made available in significant enough sections that progress can be made effectively.

There is a balancing act between maintaining appropriate safety to the workers on-site and ensuring that large enough workfaces can be accessed to make the construction practical.

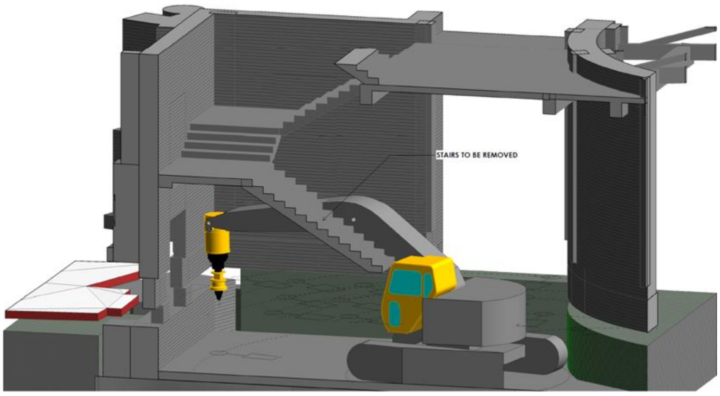
Where this risk exists, the designers and the contractor’s temporary works Engineers need to work very closely to ensure the building always remains safe for the workers. This may impose restrictions on the amount of work able to be done at any time. Rules need to be set and understood, so it is very important these and other assumptions on which the design is based are clearly laid out. Sometimes this requires some change to the design, sometimes it requires an alternative methodology to that which was anticipated by the designer or the contractor.

2.3 INSTALLATION OF SCREW PILES

The seismic strengthening design involves installation of a network of over 450 screw piles. These screw piles needed to be installed with heavy machinery across the entire building area. The constrained nature of the site with buildings on three sides, and multiple obstacles within the building created many challenges for access into and around the site. One of the first challenges for the Contractor was to devise a plan to move machinery around the Town Hall whilst minimising the impact on the existing heritage fabric.

Naylor Love were able to complete this by modelling the route of the machinery utilizing Building Information Modelling (BIM). This process helped to identify the most efficient and least obtrusive routes through the Town Hall. This process was also beneficial in preventing the machinery from being “trapped” inside the building behind completed permanent works.

The BIM modelling also identified existing building elements which obstructed the installation of the screw piles. With this knowledge ahead of time, the Contractor could discuss mitigation measures with the Heritage Architect early and help prevent delays on-site. Areas with insufficient head room for installing the screw piles were identified early and the piles were either re-located or additional demolition was completed.

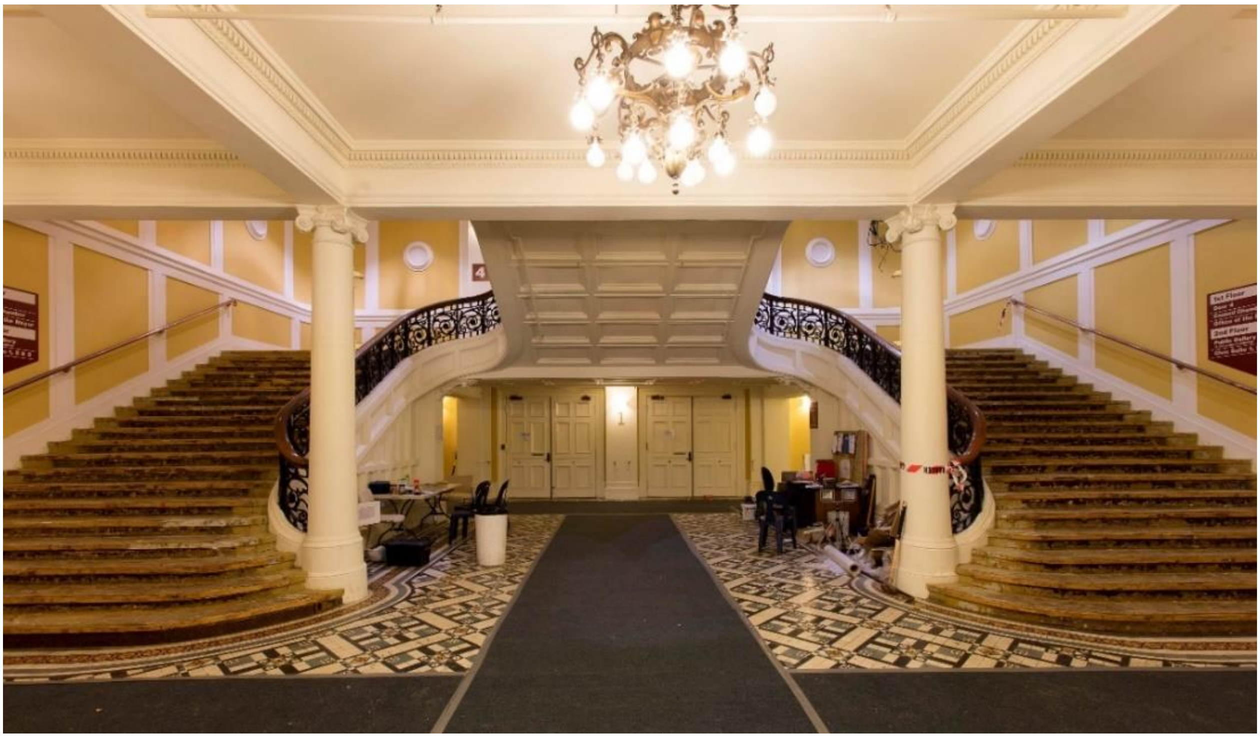


[Figure 6] BIM model showing existing stair way impeding installation of screw piles

During the BIM process, other heritage items were identified as impacting on the construction and needed to be removed. The grand stairs at the Main Foyer were originally not noted as demolition scope. The foundation design required installation of several deep steel screw piles beneath the stairs. The piling equipment could not operate in the limited head room available or access the spaces opposite to install piles as intended by the design. The detailed sequence developed with the aid of modelling showed that either the stairs needed to be demolished and replaced, or the foundation design needed to be amended. Following a review by the consultants, it was deemed too difficult to re-design the foundations and hence the main stairs were demolished and will later be replaced in replica.

Other innovations were used during the screw pile installation to allow for the site constraints and limited head room. A smaller 25-ton excavator with a modified "weighted" boom was used to reduce the size of the machinery required. Specialist machinery was also imported from Italy that was able to auger through the centre of the screw pile to break up the ground at depth, allowing the screw piles to reach their targeted depth.

[Figure 7] Modelled route of machinery and reality. There is about 50mm clearance either side of the digger



[Figure 8] Main staircase prior to construction

[Figure 9] Main staircase during construction

2.4 EXISTING BUILDING CONDITION

There are many unknowns when working on a heritage structure such as the Town Hall. During the design stage, many assumptions are made that need to be confirmed during the construction stage. Much of the original structure was undocumented and even 1990's work did not have complete structural drawings.

As noted above, the designs for structural upgrade of Heritage buildings are generally presented as "finished case". Also, because the building is often occupied through the design phase, the design has many assumptions built in. Even when some intrusive demolition, testing and investigation has been undertaken, many unknowns will remain:

These will include:

- Building dimensions and position on site
- Asbestos or other contaminants
- Building condition - Physical condition for re-use of elements
- Building condition - Effect of past alterations
- Compliance with as-built information
- Existing building services route and condition, especially in-ground

As part of the non-structural demolition for the Town Hall, the original breeze concrete floor was uncovered in the northeast corner of the building at level 1. The condition of this floor was worse than anticipated with large cracks very apparent and the ability of the floor to sustain the construction and permanent loading was in question. This discovery required emergency propping to be installed in this area while the structural design was updated to include additional catch frames. This additional propping and engineering design affected the construction sequence and ultimately had a negative impact on the construction programme and budget.

[Figure 10] Cracks uncovered in concrete Breeze Floor prior to remediation

Understanding the actual geometry of the building is a key risk mitigation. It is highly recommended that all projects in existing buildings should incorporate an enabling period at the start of the physical works to allow for confirmation of as many unknowns as possible. This can be done with a reduced site team and specialist trades to limit project costs.

This enabling period would most sensibly be done following the non-structural demolition when base structure and structural lines are exposed. It would necessarily include a detailed and intrusive asbestos survey. It may also include digital scanning to allow comparison with design models, and adjustment of the design as required and as part of that should include tracing of key services for inclusion in that model. The contractor cannot do much without clear and coordinated dimensioned drawings. The importance of verifying the design model and design assumptions on site cannot be understated.

2.5 BUILD SEQUENCE

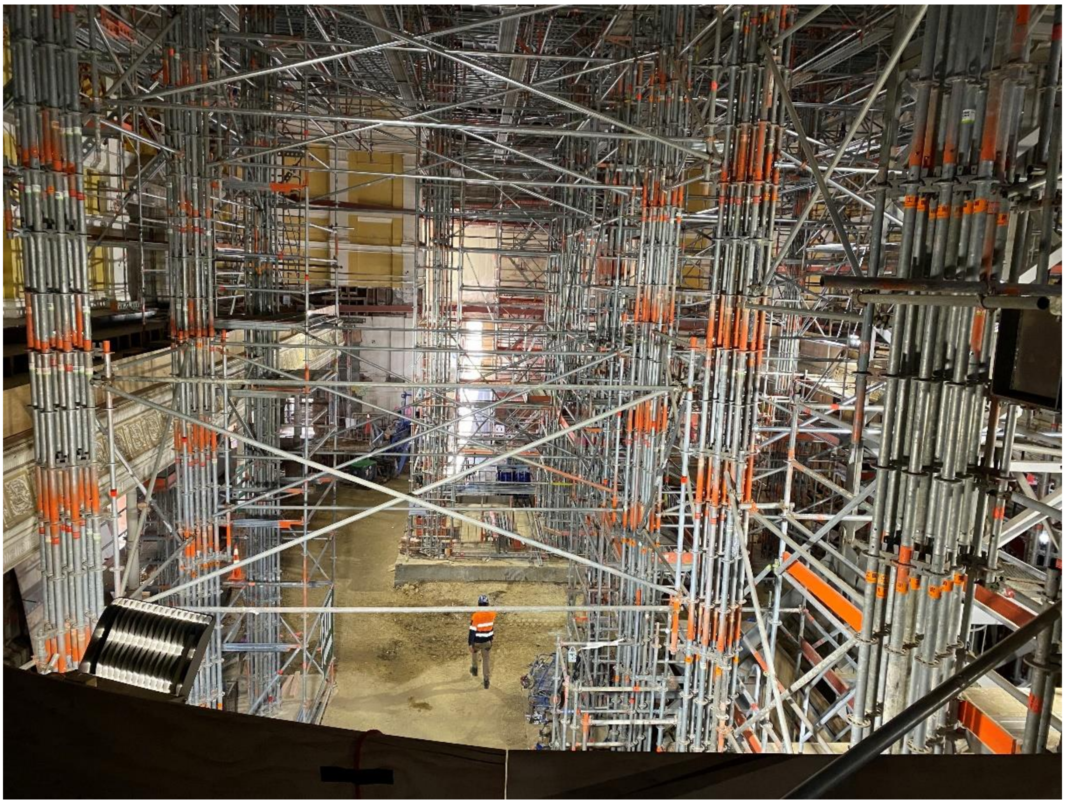
In a new build, the process usually starts with the foundations and finishes with the roof. For a seismic retrofit, it is not so simple, as works in one area may affect the safety of workers in another area. Major structural upgrades requires a considered sequential engineered approach to ensure that building and worker safety is not compromised.

The process by which the building transitions from a 120-year-old earthquake prone building to a 100% NBS IL3 base isolated structure requires significant co-ordination between the Contractor and the Structural Engineer.

Most Contractors will assume multiple workfaces, across different areas and multiple levels as this is the most efficient construction practice and results in the earliest completion date for the client. This requires a detailed understanding of the interplay between different elements of work.

Most consultant's designs do not portray the strict sequence required for the works and it is often best left to the Contractor to programme the works as they best see fit. Similarly for the Town Hall, no strict sequence of works was provided but instead a series of parameters were required to be met during construction. These key parameters include:

- No more than 25% of the lateral capacity of the building on any structural line could be removed at any one time. This placed limits on the size of concrete pours that could be achieved for the raft slab and ground beams and needed a lot of iteration to ensure details such as reinforcing lap zones could be properly managed.
- Sheet piling for the new basement could only start after completion of the ground beams and loading of the isolators. This constraint limits the risks of the sheet piling vibration damaging the original 1904 concrete piles. This created a milestone for the project where effectively the auditorium basement could not begin until full completion of the upper foundation structure.
- The designers assumed that the foundations and isolation works would be completed first, with works progressing upwards. As the contractor, we had allowed for a top down, bottom-up construction sequence where works will proceed at multiple levels. A compromise was reached wherein works to upper levels could proceed under strict loading restrictions.
- Propping of all the Auditorium trusses was required during strengthening as the existing timber trusses were not capable of supporting the construction loading. This resulted in unplanned propping through the auditorium, landing on temporary concrete pads. These truss props were spaced to maintain access routes through the auditorium for equipment and materials.



[Figure 11] Truss propping through the auditorium

Some of these constraints were obvious at tender time and other constraints only became clear as the works proceeded, and the building condition was revealed. The iterative development of an agreed sequence and final scope to manage the effect of these unforeseen elements has impacted on programme.

This is a shared risk that can only be daylighted through the detailed design of the sequence and temporary works. It is important that the contactor and consultants share their assumed construction sequences as soon as practical so that any differences can be resolved, and the construction programme updated accordingly.

2.6 SEISMIC GAP CUTTING

Of particular importance for a seismic retrofit that incorporates base isolation is the timing of the seismic gap creation. The seismic gap separates the rigid lower raft foundation from the ground beams which are directly supported by the base isolators. See figure 5 above.

Prior to the cutting of the isolation plane, the building remains a rigid, URM structure with associated low ductility and low displacements. Following completion of the foundations, loading of the isolators, and cutting of the isolation plane, the building transitions to a more flexible building with associated higher damping and larger displacements.

In an ideal world, the timing between the first cut and last cut would be instantaneous so that either the building acts in its rigid or flexible state. However, in reality, the cutting process can take a number of months with the building in a semi rigid / semi flexible state as the cutting proceeds.

It would be impractical to assess the building at each stage of cutting to assess its seismic capacity and therefore some key parameters need to be agreed between the Contractor and Structural Engineer so that works can proceed efficiently.

For the Town Hall, both parties worked together to derive a foundation sequence that would limit the risks associated with the cutting process. The foundation sequence was an iterative process by which the Contractor tracked the constructability, and the Engineer prepared a risk assessment of the structural elements at the interface of the rigid / flexible foundations.

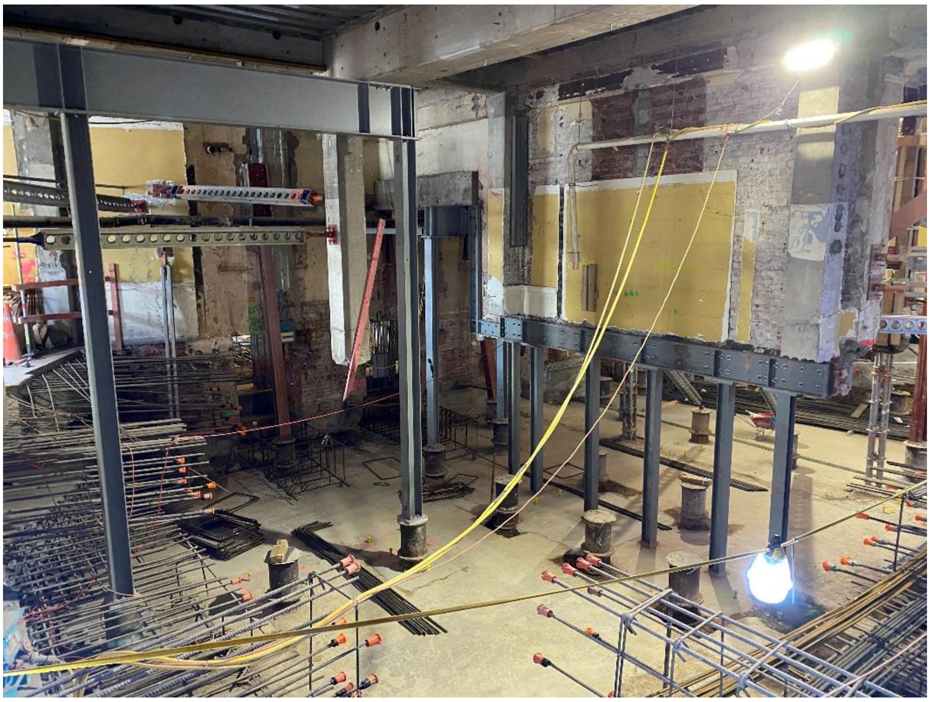
2.7 SURVEYING AND BUILDING MONITORING

Surveying plays an important role in the retrofit of an earthquake prone building. For the Town Hall structure we constantly review whether the works adversely affect existing structure. This is particularly important beneath the external URM piers and internal URM walls where temporary vertical propping is installed to allow for construction of the new raft foundations and ground beams. During these works, the existing structure is monitored regularly to check for any deviations from the baseline completed prior to construction.

The brittle URM walls and existing concrete piles were identified as potential risk items at the start of construction and special consideration is provided to limit the impacts of the construction works on these items. The Structural Engineer has provided tolerable and evacuation deflection limits that the Contractor regularly monitors against.

In addition to the regular surveying, the Town Hall construction also incorporates a number of tilt sensors which provides real time measurements of selected walls for in-plane and out-of-plane movement. These tilt sensors are calibrated to the tolerable and evacuation limits set by the Structural Engineer and an emergency text is provided to senior site management when the targets approach these values.

The existing piles date back to the original 1904 construction and are considered extremely brittle. During the 1900's work, local disturbances to the soil resulted in the separation of one of these concrete piles along the North wall. This then required emergency remedial works to stabilise the structure, highlighting the vulnerability of the foundation system to even modest movement.



[Figure 12] Regular surveying for temporary propping supporting existing URM walls and concrete columns prior to forming raft slab

2.8 HERITAGE ELEMENTS

Before structural works can commence, we determine which heritage fabric needs to be removed or protected based on documentation from the client and heritage Architect. Any items removed are stored off-site in a nearby storage facility. Each item removed is fitted with a barcode which can be scanned to reveal where the item came from.

A point cloud scan as well as Building Information Modelling (BIM) was utilised to record the exact building condition and heritage layout at the start of the project. A dilapidation survey was also completed before works began on-site to determine the existing condition of the building. Multiple existing issues, such as warped doors or missing rails were logged in the system for future reference.

[Figure 13] Photograph and point cloud data of the main stair before demolition. This digital data will be used to make the moulds for rebuilding the stair. Ref also figs 8 and 9

For any structural works which affected heritage fabric, multiple construction methods were considered and rated to minimise the impact on these items. Heritage fabric that remained in place during construction were protected from minor strikes (such as accidently being struck with a ladder) or a larger strike (such as being hit by passing machinery).

The bluestone on the external face of the building is an integral part of the building's heritage fabric. The bluestone was required to be removed to allow for construction of the new ground floor beams. Detailed investigatory works were complete to determine a suitable methodology to protect the bluestone during removal and re-instatement.

[Figure 14] Exterior of building showing bluestone plinth at base

The choir stalls in the north auditorium were carefully catalogued and removed to allow for installation of the screw piles and excavation for the basement. The stalls were effectively de-constructed piece by piece so that they could later be re-constructed exactly as before.

3.0 TEMPORARY WORKS

Temporary works include parts of the works that allow or enable construction of the permanent works. This includes the works required to protect, support, or provide access to the permanent works. As the Town Hall involves the construction of a new foundation system, the temporary works and stabilisation requirements have been a major challenge.

3.1 CREATING ACCESS

One of the first major challenges for construction was creating access for machinery into all areas where demolition or major structural works are occurring. There were no existing openings large enough at the start of construction, so an access way was created through the existing URM wall from Wakefield Street. This opening provided the main access into the site during the construction works and will be filled with reinforced concrete at the end of construction.

[Figure 15] Openings in URM wall for access and equipment needed inside

3.2 MAINTAINING GRAVITY LOAD PATHS

The structural retrofit design for the Town Hall involves re-founding all the external URM piers onto new concrete ground beams. To accomplish this, temporary UC columns were progressively installed below the piers to enable the demolition and construction of the new ground beams. We worked closely with the structural engineer to determine the transition of the loads from its current state into the temporary works and then through into the new permanent structure. These UC piers were later cast in with the permanent works ground beams.

Further BIM modelling was used to ensure that the temporary works props did not interfere with placement of the base isolators. The temporary props were also placed to minimise the impact on the reinforcement within the permanent works ground beams.

Similar temporary works propping was completed inside the Town Hall where existing structure was being re-founded onto new ground beams.

[Figure 16] Temporary works UC props, later cast in with permanent works ground beams

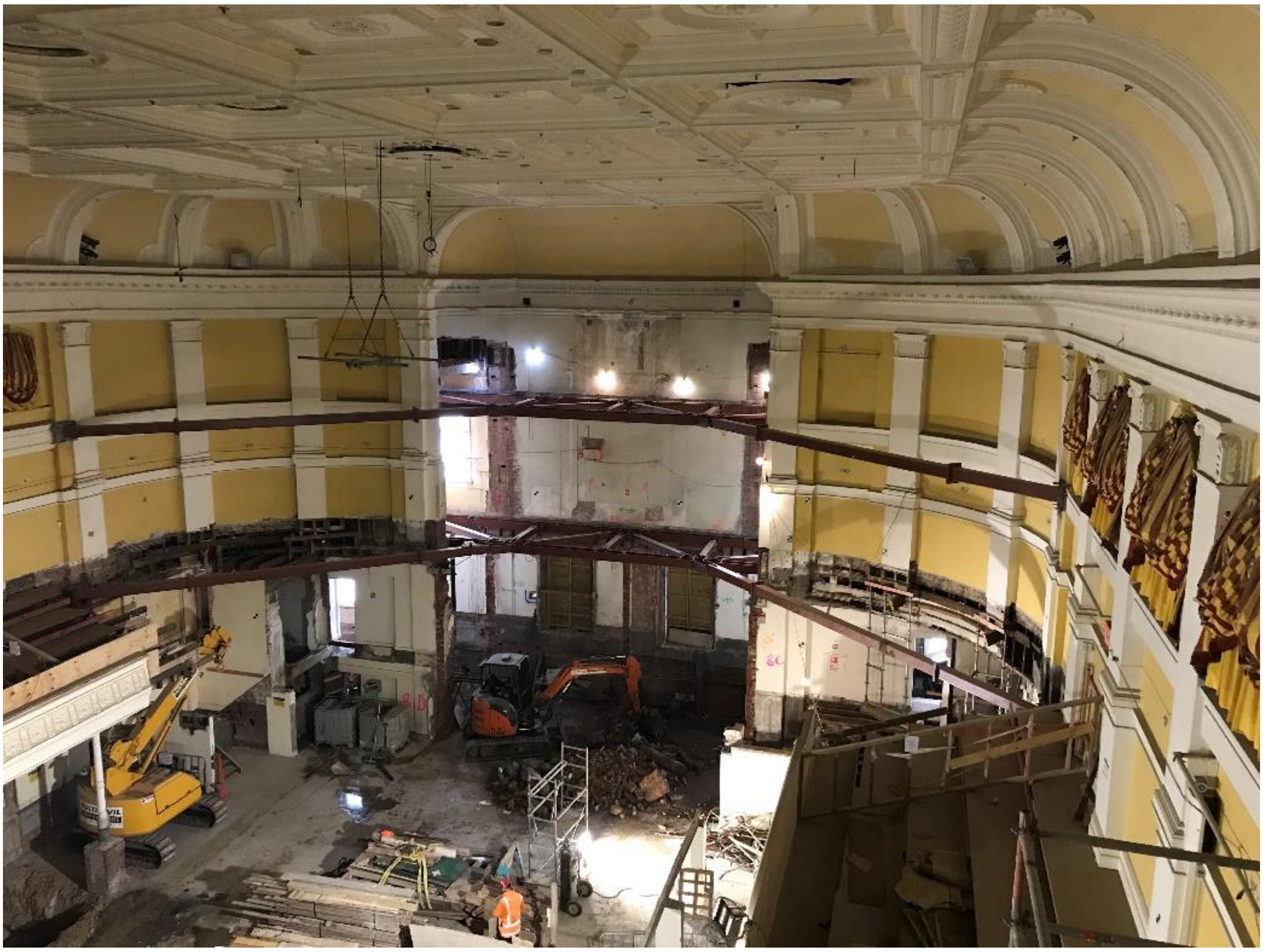
3.3 LATERAL STABILITY

At multiple locations around the town hall, existing diaphragms had to be removed to allow for construction of the permanent works. Temporary lateral propping was then required to provide out of plane restraint to the existing URM walls.

AS/NZS 1170.0 requires that temporary works for construction are designed for a 100-year return period event. Seismically prone buildings may not be able to withstand this loading, but when we design temporary works to support the buildings, these elements need to be designed to the code. This creates some philosophical design issues which are not always easily resolved.

This difference is seen most obviously when the project requires removal of lateral resisting elements (usually unreinforced brick walls) and designing “replacement capacity” propping or similar. The code requires designing for the 100-year event, whereas logic suggests that we should only replace the capacity that has been removed.

At the Wellington Town Hall we started the project rigidly applying the code, with some heavy temporary works as a result. As the project progressed and the ability to provide that level of support diminished, the temporary works designs were tuned more to matching building performance in terms of strength and stiffness.



[Figure 17] temporary lateral stability to North Wall

Along the north wall of the auditorium, existing timber floors and perpendicular URM walls were removed to allow access for the screw pile machinery. Removal of this structure reduced the out of plane capacity of the remaining structure as the external URM walls were effective laterally unsupported from the foundations to the roof. Propping of this wall was a major challenge due to the lack of remaining structure that the propping could be founded on. As a result, it was decided to brace the north wall back to the long URM walls around the perimeter of the Auditorium. This required construction of a two significant horizontal steel trusses to temporarily support the north URM wall during construction. It is planned to remove these trusses as the new permanent works are completed.

For the main loadbearing URM walls the ground floor beams were cast in contact with the brick wall below to maintain the shear capacity of the wall, ref fig 18. On other internal lines, we cast temporary concrete shear blocks between the ground floor and foundations that will be removed as part of the seismic gap cutting sequence.

[Figure 18] shear capacity of the exterior walls was managed within the concrete works

3.4 EXTERNAL COLONNADE

The elevation along Wakefield Street contains 4 prominent URM columns. The structural retrofit design involves installation of 50mm diameter stressbar through the centre of the columns and installation of a new foundation and sliding bearing at the base of the columns.

The proposed strengthening works created some significant challenges for the Contractor, as we needed to disconnect the base of the columns to construct the new foundations but there was no obvious solution to support the weight of the 12m high columns while this work was underway.

After exploring a number of solutions, it was decided to utilise a temporary steel truss to support the URM columns. The steel truss was supported by six UC columns which were founded on top of the new screw piles. This solution enabled the new foundation works to proceed whilst maintaining the strict settlement deflection limits set by the Structural Engineer.

[Figure 19] Colonnade along Wakefield Street prior to construction

[Figure 20] Colonnade temporary truss in place after demolition of the column foundations

4.0 CONCLUSION

This paper focuses on the protection of heritage and seismic strengthening of the Wellington Town Hall. We outlined the history of the Wellington Town Hall as well as some of the heritage features that has contributed to the building's Category 1 rating from Heritage New Zealand.

The paper outlined some of the construction challenges and unique temporary works solutions required to complete the proposed seismic strengthening. The proposed construction sequence and required temporary works can equally affect the heritage fabric for a seismic retrofit as much as the proposed seismic strengthening works.

It is important that constructability is foremost in mind when completing the seismic strengthening designs for such buildings. It is recommended that an experienced Contractor is engaged as soon as practical to advise on how the construction work will best proceed, and how risks will be allocated or managed. Such key decisions are typically only reached following an iterative design and discussion process between the Client, Contractor, and the Consultants. This required process is almost impossible to complete within a standard narrow tender period. An engaged and pragmatic team is crucial for completing such a complex and challenging project.

For projects with significant structural or building services upgrade there must be decisions made about the level of impact on Heritage fabric that can be accepted. Many such buildings have been "upgraded" at various times in their lives, so decisions about what is considered Heritage Fabric must be made and reviewed constantly throughout the project's life. The requirement for significant structural work usually requires major demolition and rebuilding, which can impact on a wider Heritage scope than the design contemplates.

5.0 REFERENCES

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WORKING WITH COMMUNITIES TO PRESERVE HERITAGE STRUCTURES

engineering new zealand HERITAGE

WORKING WITH COMMUNITIES TO PRESERVE HERITAGE STRUCTURES: WRITER BIOS

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engineering new zealand HERITAGE

SIMPLE STRENGTHENING: AN OUTLINE OF A NON-SPECIFIC DESIGN APPROACH FOR UNREINFORCED MASONRY BUILDINGS IN AOTEAROA/NEW ZEALAND

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Note the views expressed in this paper are the authors' alone and do not necessarily express the views of Holmes Consulting.

Summary: A significant proportion of Aotearoa/New Zealand's Earthquake-prone buildings (EPBs) are constructed from unreinforced clay brick masonry (URM). These buildings can be found in cities and towns and tend to be clustered into precincts. Current research suggests that many of these buildings are at risk of not receiving seismic strengthening, particularly those sited in regional communities. In the short term, the seismic risk from these buildings is not being mitigated, while in the long term widespread demolition and abandonment is predicted, with consequent economic and social harm to communities. A reduction in cost and a streamlining of the retrofit process may improve uptake of strengthening and reduce negative socioeconomic outcomes. One advantage that the majority of URM buildings possess is that they are typologically similar and were constructed with a relatively standard set of methodologies. Therefore, one option to lower the barrier to entry for strengthening and securing of URM buildings conforming to certain parameters is to provide a non-specific retrofit scheme. The intent is that the scheme could be applied by licenced building practitioners without specific engineering input, or with limited engineering input directed towards specific elements of structures in high-hazard areas. This paper presents an overview of a possible non-specific strengthening design method for URM buildings, and provides examples of the types of sorting methods that could be applied to assign strengthening measures to specific structures. Brief consideration is also given to minor required changes in the regulatory framework which would support the continuing use of these buildings once they are strengthened.

INTRODUCTION

Unreinforced clay brick masonry buildings are a common sight along the shopping streets of Aotearoa/New Zealand's cities and towns [1]. In the years since the Canterbury Earthquake Sequence, an increased national focus on seismic resilience has seen many of these buildings designated as earthquake prone [2]. As territorial authorities report on earthquake prone buildings (EPBs) in their areas, individual properties are listed in the publicly available Earthquake-Prone Buildings Register. The Register's maps of earthquake-prone buildings reveal the intertwined issues faced by owners and by the communities in which the buildings are sited (for example, see Figure 1). For owners, the Earthquake-prone Buildings Amendment Act (EPB Act) sets out a process of building-specific assessment and bespoke strengthening. These legislative requirements sit alongside other legal and market-related drivers, including the availability and cost of earthquake insurance for earthquake-prone buildings, the market demand for earthquake-prone buildings, and legislative commitments such as those related to the Health and Safety at Work Act 2015. For communities, the potential loss of buildings in clusters in their commercial centres presents a pressing challenge to the continuing provision of social and economic amenity.

A number of New Zealand researchers have investigated the likely outcomes of the current settings for the management of earthquake prone buildings. This research was reviewed briefly in Tocher and Cutfield [3]. A key finding is that for many owners of EPBs, inaction on earthquake strengthening followed by building demolition appears to be the most likely outcome [4-6]. This pathway leads to financial loss for owners and negative social consequences for communities. The major issue identified by the research appears to be that the cost of strengthening is high relative to the asset value of the buildings and their ability to generate revenue.

[Figure 1] Examples of regional centres as shown in the EPB register, with orange markers representing a known EPB (left: Feilding; right: Ashburton).

To increase the uptake of seismic strengthening, one possible policy option would be to increase the level of government funding for strengthening of earthquake prone buildings, acknowledging that the general public benefits from this spending through the resulting reduction of risk to life. MBIE's initial evaluation of the earthquake-prone building system, published earlier this year, acknowledges the disproportionate challenge faced by building owners in regional Aotearoa/New Zealand. The report notes the effective and 'proactive' role that government funding through Heritage EQUIP plays in supporting the strengthening of the subset of earthquake-prone buildings which have been designated with heritage status [7]. However, since the MBIE report was published, government seismic upgrade incentives through the Heritage EQUIP fund have been suspended and no further money was allocated to the fund in the 2021 Budget [8].

This paper suggests that an alternative approach to increase uptake of seismic strengthening (while reducing the negative socioeconomic impacts of doing so) would be to make use of standard strengthening details. The intent of the proposed scheme is to reduce costs for owners and to direct their available resources towards making physical improvements that reduce the most critical seismic risks posed by the building. We suggest that the current requirement to analyse and assess the response profile of individual URM structures could be replaced with a non-specific design process in many cases. The result would be somewhat analogous to what is currently provided in New Zealand's non-specific timber-framed building standard, NZS 3604:2011, and non-specific concrete masonry standard, NZS 4230:2004. The adoption of a non-specific design approach would allow a pathway for owners to move directly from the identification of their building as earthquake-prone to a programme of strengthening and securing works. If standard details were to be pre-consented for installation by a licenced building practitioner, a reduction in programme time and regulatory costs may also provide an incentive for strengthening.

In support of the feasibility of non-specific design for URM building strengthening, recent research and engineering guidance published by both national and local bodies has noted the relative homogeneity of Aotearoa/New Zealand's URM buildings, both in terms of building typology and structural detailing [9, 10]. The probable failure modes of URM buildings are also well established in engineering research and practice. Standard details for mitigating the risks inherent in these failure modes have been published [11]. However, one element missing from the current toolbox is a non-specific design methodology designed to assign a package of the existing standard details to qualifying earthquake-prone buildings. This paper provides an outline of what a non-specific design system could look like. In this paper, the non-specific design methodology is termed 'simple strengthening'.

SIMPLE STRENGTHENING PROPOSAL

Under the simple strengthening approach, URM buildings meeting certain criteria would be strengthened using standard details without specific engineering input (or with limited input) and be otherwise exempted from the requirements of the EPB Act. Central to this approach is the non-specific design scheme which allows relevant standard details to be chosen for use on a given structure. The following section outlines the proposed non-specific design scheme in terms of its objectives, eligibility criteria, and the determination of required structural interventions. The simple strengthening process is summarised in Figure 4.

Structural objectives

The objectives of a simple strengthening approach are as follows:

- Intervene in the building to mitigate against the risk of structural collapse in a moderate earthquake.
- Adopt pragmatic rule-of-thumb solutions to reduce risk from probable failure modes of URM buildings. For example, strengthening each joist-to-wall connection using a cost-effective and practical standard detail rather than determining the number of joist-to-wall connections which may be required and designing a bespoke connection on a case-by-case basis.
- Adopt a suite of strengthening measures likely to be broadly similar to those which would have been designed as part of a bespoke assessment.
- Strengthening measures installed should be able to serve as part of a future bespoke strengthening, if future strengthening were carried out.

Refer to the **Legal and Regulatory Framework Update** section for further detail on how the simple strengthening philosophy aligns with the Regulations of the EBP Act.

Typology A building – one storey isolated.

Typology B building – one storey row.

Typology C building – two storey isolated.

Typology D building – two storey row.

[Figure 2] Eligible buildings. Reproduced from Ingham and Russell (2010) with permission.

Eligible buildings

The buildings that this proposal targets are the typical one- and two-storey commercial/residential structures seen in the main streets of regional Aotearoa/New Zealand. These buildings fit within Typologies A-D as defined in Russell and Ingham [1] (see Figure 2). Larger, more structurally complex URM buildings like churches and multi-storey masonry buildings in urban centres are excluded from simple strengthening, as their seismic response is generally more difficult to capture within a set of standard rules. Under the simple strengthening scheme, URM buildings eligible for standard detail strengthening would be defined by a specific set of criteria, such as:

- Lateral load resisting system constructed of unreinforced clay brick masonry (i.e., not RC frame buildings with brick infill) with a minimum length of wall in each direction
- Located in an area with hazard factor (Z) per NZS 1170.5:2004 not greater than a threshold value around 0.45
- No more than two storeys tall (basement not included)

- Wall lengths, inter-storey heights and diaphragm spans not to exceeding given threshold values (refer following sections for further discussion)

These criteria have been set as a starting point to capture buildings within the target group. It is noted that further work would be needed to refine these if a “simple strengthening” scheme were to be implemented.

The simple strengthening approach is intended to provide appropriate and robust strengthening for a significant proportion of Aotearoa/New Zealand’s URM buildings. While some buildings will evidently be suitable for simple strengthening (for example one-storey shops in low-seismic regions like Auckland and Northland), others will equally evidently be unsuitable (for example large churches in high-seismic regions like Wellington). This leaves a third set of URM buildings which are “edge cases”. For these buildings, it is less clear whether simple strengthening should be applicable. As noted later in this paper, some buildings falling into this third category will be identified through the *conditional measures* portion of the simple strengthening process, which may determine that a building that appeared to be eligible for simple strengthening does in fact require some specific engineering input (at least for selected atypically complicated elements). Although full details of the management of edge cases is outside the scope of this paper, we note that a potential option would be to allow engineers to provide specific professional judgement to augment simple strengthening, in a manner similar to the design of large lintels or other non-standard elements deemed “SED” (requiring specific engineering design) in NZS 3604:2011. An example might be clarification of appropriate diaphragm boundaries to which simple strengthening rubrics can be applied, or strengthening design for an atypically complicated diaphragm.

A central aim of simple strengthening is to assist owners of regionally located URM buildings (for which the ratio of strengthening cost to building value tends to be highest) to continue to operate their buildings and serve their communities. A maximum capital value could be applied as a screening tool to help define target URM buildings that are eligible for simple strengthening [3]. However, as a broad policy measure, it is noted that it would be simpler and more consistent to permit all typologically eligible URM buildings to access simple strengthening measures (regardless of capital value or location), and then allow for market drivers to incentivise further strengthening and renovations for those buildings that are able to financially support additional works.

Simple strengthening measures

The proposed simple strengthening measures can be divided into two categories. The first category is the **baseline measures**, which would be applied to all buildings carrying out seismic improvement in accordance with the simple strengthening rubric. The **baseline measures** are:

- Parapets and ornaments to be restrained or removed.
- Roof structure to be connected to walls at each rafter and at regular centres along gables and walls parallel to rafters, with appropriate detailing.
- Floors to be connected to walls at each joist and at regular centres along end joists parallel to walls, with appropriate detailing.
- Cavity walls to be tied together with cavity ties at regular centres.
- Canopy connections (and/or local zones around canopy connections) to be reviewed and strengthened.

The second category, **conditional measures**, would apply to some buildings, depending on their geographical location and physical characteristics. Strengthening requirements would be determined using simple lookup tables similar to those that are used under NZS 3604:2011. The **conditional measures** are:

- Timber strongbacks to be added to masonry walls for out-of-plane restraint.
- Diaphragm strengthening by adding plywood and/or additional nailing.
- Chimneys to be braced or removed.

The choice of the above set of baseline and conditional measures is explored in greater detail in Tocher and Cutfield [3].

Out-of-plane wall strengthening

Under a simple strengthening scheme, requirements for the strengthening of URM walls out-of-plane would be determined using lookup tables with the following input parameters:

- Wall height (vertical span distance between points of support)
- Location in the building (for example, the second storey of a two-storey building)
- Wall thickness
- Hazard factor (Z-factor)

Additionally, strengthening requirements would apply only to walls with a significant length between restraining return walls, and where the collapse of those walls would be likely to lead to structural collapse, either by a direct loss of vertical load-carrying capacity, or by a significant loss in lateral stability.

Table 1 provides an example lookup table for a single-wythe, 110mm thick URM wall in a one-storey URM building. The table includes simple strengthening requirements in the form of timber strongbacks at various sizes and spacings.

Most regular URM buildings in New Zealand's lower hazard regions (such as Northland, Auckland, Waikato, Coromandel, and coastal Otago) would not require any out-of-plane wall strengthening as part of a simple strengthening scheme. However, requirements for out-of-plane wall strengthening would become more stringent as the level of seismic hazard increases, to allow for the increasing risk of out-of-plane wall failure leading to structural collapse. In high hazard areas like Wellington, most URM masonry walls would be expected to require some form of out-of-plane strengthening.

It is noted that a few walls at the upper end of the height and hazard range may not be suitable for retrofit using simple strengthening measures. These walls would be denoted as requiring "SED" (specific engineering design). Where buildings are determined to contain walls of this type, they will not be automatically eligible for simple strengthening. However, with baseline simple strengthening measures plus engineering input directed towards strengthening specific non-complying elements, they could be deemed to achieve a performance level sufficient for exemption from the EPB Act (refer to Legal and Regulatory Framework and to the section below on %NBS for further discussion).

Z-value	Example cities/towns	Wall height (m)							
		≤ 2.4	≤ 2.7	≤ 3.0	≤ 3.3	≤ 3.6	≤ 4.0	≤ 4.5	≤ 5.0
≤ 0.10	Whangarei, Kaitaia, Kaikohe, Dargaville	-	-	-	-	-	-	-	-
≤ 0.13	Auckland, Dunedin, Oamaru, Mosgiel	-	-	-	-	-	-	-	-
≤ 0.16	Thames, Huntley, Hamilton, Timaru	-	-	-	-	-	-	-	-
≤ 0.19	New Plymouth, Te Kuiti, Matamata, Invercargill	-	-	-	-	-	-	-	140x45 at 1200mm spacing
≤ 0.22	Tokoroa, Taumaranui, Ashburton, Alexandra	-	-	-	-	-	-	90x45 at 600mm spacing	140x45 at 1200mm spacing
≤ 0.25	Whanganui, Rotorua, Cromwell, Fairlie	-	-	-	-	90x45 at 900mm spacing	90x45 at 600mm spacing	140x45 at 1200mm spacing	140x45 at 1200mm spacing
≤ 0.3	Whakatane, Taupo, Christchurch, Nelson, Picton, Westport	-	-	90x45 at 900mm spacing	90x45 at 900mm spacing	90x45 at 600mm spacing	90x45 at 600mm spacing	140x45 at 1200mm spacing	140x45 at 1200mm spacing
≤ 0.35	Taihape, Bulls, Blenheim, Rangiora	90x45 at 1200mm spacing	90x45 at 900mm spacing	90x45 at 900mm spacing	90x45 at 600mm spacing	90x45 at 600mm spacing	140x45 at 1200mm spacing	140x45 at 1200mm spacing	140x45 at 900mm spacing
≤ 0.4	Napier, Hastings, Feilding, Palmerston North, Levin, Wellington, Greymouth, Te Anau	90x45 at 1200mm spacing	90x45 at 900mm spacing	90x45 at 600mm spacing	90x45 at 600mm spacing	90x45 at 600mm spacing	140x45 at 1200mm spacing	140x45 at 900mm spacing	140x45 at 900mm spacing
≤ 0.45	Waipukarau, Masterton, Kaikoura, Hokitika	90x45 at 900mm spacing	90x45 at 600mm spacing	90x45 at 600mm spacing	90x45 at 600mm spacing	140x45 at 1200mm spacing	140x45 at 900mm spacing	140x45 at 900mm spacing	140x45 at 600mm spacing

[Table 1] Example lookup table providing strengthening requirements for a single-wythe, 110mm thick masonry wall in a one-storey masonry building. Blue-shaded cells identify arrangements where strengthening is required. Strengthening is specified as an MSG8 timber strongback size with an accompanying spacing.

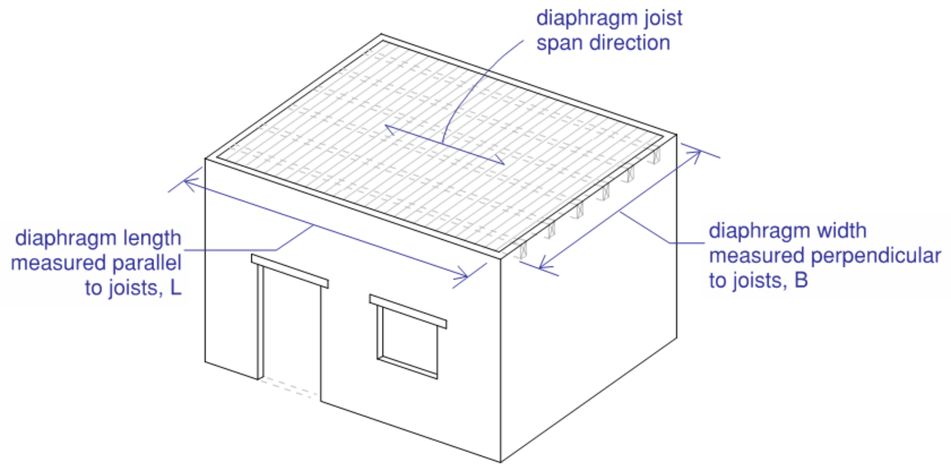
Diaphragm strengthening

Requirements for the strengthening of flexible timber diaphragms would also be determined using lookup tables, with the following input parameters:

- Wall height (above and below the diaphragm)
- Wall thickness (above and below the diaphragm)
- Diaphragm size (length and width)
- Hazard factor (Z factor)

Clear guidance would be provided to users around how to measure the diaphragm length and width (for example, see Figure 3), as well as maximum degrees of penetration in the diaphragm and adjacent walls for which a simple strengthening approach would be applicable.

[Table 2 shows example lookup tables for requirements for the first floor timber diaphragm in a two-storey URM building with a typical wall height of 3.5m and a typical wall thickness of 110mm. Lookup tables are provided for two regions, both with a relatively high level of seismic hazard: firstly, the Z-value range 0.25 - 0.30 (e.g., this would apply to cities/towns such as Whakatane, Taupo, Christchurch, Nelson, Picton and Westport); and secondly, the Z-value range 0.35 – 0.40 (e.g., this would apply to cities/towns such as Napier, Hastings, Feilding, Palmerston North, Levin, Wellington, Greymouth and Te Anau). Diaphragm strengthening would not generally be expected for areas of lower seismic hazard (such as Auckland, Northland, Waikato and Dunedin) unless the set out of those diaphragms was highly unusual, or if diaphragms were highly penetrated.



[Figure 3] Isometric sketch of a simple URM building showing how diaphragm length and width are measured.

(a)

Hazard class Z = 0.25 - 0.30		Diaphragm length, L (m)							
		≤ 3	≤ 4	≤ 5	≤ 6	≤ 7	≤ 8	≤ 9	≤ 10
Diaphragm width, B (m)	≤ 3						re-nailing	plywood overlay	plywood overlay
	≤ 4							re-nailing	plywood overlay
	≤ 5								re-nailing
	≤ 6								
	≤ 7								
	≤ 8								
	≤ 9								
	≤ 10								

(b)

Hazard class Z = 0.35 - 0.40		Diaphragm length, L (m)							
		≤ 3	≤ 4	≤ 5	≤ 6	≤ 7	≤ 8	≤ 9	≤ 10
Diaphragm width, B (m)	≤ 3					plywood overlay	plywood overlay	plywood overlay	plywood overlay
	≤ 4						plywood overlay	plywood overlay	plywood overlay
	≤ 5						re-nailing	plywood overlay	plywood overlay
	≤ 6							re-nailing	plywood overlay
	≤ 7							re-nailing	plywood overlay
	≤ 8								re-nailing
	≤ 9	plywood overlay							re-nailing
	≤ 10	plywood overlay	re-nailing						re-nailing

[Table 2] Example lookup table providing simple strengthening requirements for a URM building flexible timber diaphragm. The first part (a) relates to Z-values 0.25 - 0.30 and the second part (b) relates to Z-values 0.35 – 0.40. The strengthening requirements relate specifically to the diaphragm at the first floor of a two-storey URM building, where the walls above and below are both 110mm thick and 3.5m high.

Chimneys

Under the simple strengthening approach, a lookup table methodology for URM chimneys would be adopted, similar to that used for out-of-plane walls and diaphragms. The input parameters would be the hazard factor, base height and height above the roof plane of the chimney, and the chimney's width and depth.

In-plane strengthening

As noted by Tocher and Cutfield [3], in-plane strengthening has been excluded from the simple strengthening proposal, noting that URM buildings in high hazard areas with small masonry wall lengths are not considered eligible for simple strengthening. It is noted that strength-based assessments of in-plane capacity can often be supplemented with more detailed assessment approaches (such as the capacity-spectrum method or nonlinear time-history analysis allowing for hold-down restraint from return walls) to show that in-plane walls are more resilient than might otherwise be expected. Diaphragm and connection enhancements provided as part of seismic strengthening are likely also to provide additional in-plane robustness to open-fronted buildings through torsional restraint, especially in row buildings (noting specific guidance on this would be built into the simple strengthening requirements for diaphragms).

Standard details

A starting point for the set of standard details to be used for simple strengthening is given by the MBIE document *Securing Parapets and Facades on Unreinforced Masonry Buildings* [11]. A technical review of these details would need to be carried out to determine their suitability for use in a non-specific design scheme. It is intended that the standard details published for use would be geared towards implementation by local tradespeople, in a manner not dissimilar to the non-specific timber and masonry standards (NZS 3604:2011 and NZS 4230:2004).

Inspection and sign-off

This paper proposes that engineers need not be directly involved with simple strengthening of eligible URM buildings, except where specific elements require additional engineering input or judgement. For most eligible buildings, the work can be carried out by a licenced building practitioner (LBP). Inspection of the building work would be carried out by TLAs, using their existing inspection processes. As noted above, it may be possible to pre-consent standard details for use in buildings which have been deemed earthquake-prone. Both LBPs and TLAs may require support to develop the skills required to install and to monitor the use of standard details. A suitable training process could be developed with assistance from appropriate government bodies and from engineering organisations like the New Zealand Society for Earthquake Engineering (NZSEE).

Percentage of New Building Standard (%NBS)

The simple strengthening process is predicated around providing sufficient structural robustness to meet the criteria for exemption from the EBP Act (see **Legal and Regulatory Framework** below for more on this). As a result, the process does not require the determination of a %NBS score for an eligible building, since an EPB Act exemption would override any legal obligation to carry out further works.

An ISA (resulting in a %NBS score) will likely still be required to allow the local authority to determine whether a building is earthquake-prone. We note that many URM buildings have already been assessed and the determination of earthquake-prone status made [7,12]. Moreover, practical experience suggests that most URM buildings, even in relatively low seismic regions, will require some securing at a minimum. As such, determination of the precise %NBS score may not provide further useful information, and owners may wish to simply implement the simple strengthening scheme without commissioning an assessment. While any pre-existing %NBS score would no longer have legal effect on exempted buildings, market drivers for further improvement would continue to provide impetus for further strengthening work.

The simple strengthening programme is not intended to be equivalent to a specific %NBS level. Where a bespoke strengthening scheme takes a holistic and analytical approach to determining structure performance and retrofit design, simple strengthening instead takes a rule-based and pragmatic approach, seeking to ensure that the risk of collapse in a moderate earthquake is mitigated against. The *moderate earthquake* is approximated by demand equal to 34% of the ULS load, and it is on the basis of this demand that the lookup tables for the conditional measures would be determined. However, this does not mean that simple strengthening is the same as bespoke strengthening to 34%NBS. Rather, baseline measures are combined with any required conditional measures to make collapse in a moderate earthquake unlikely, and meet the threshold for exemption. Where standard conditional measures cannot be shown to achieve the collapse prevention target for a given element, specific engineering design or engineering judgement may be required to determine the best course of action. It is intended that the input from an engineer to resolve "SED" items would be at an element-only level, with a significantly lower level of analysis than that required for a bespoke scheme.

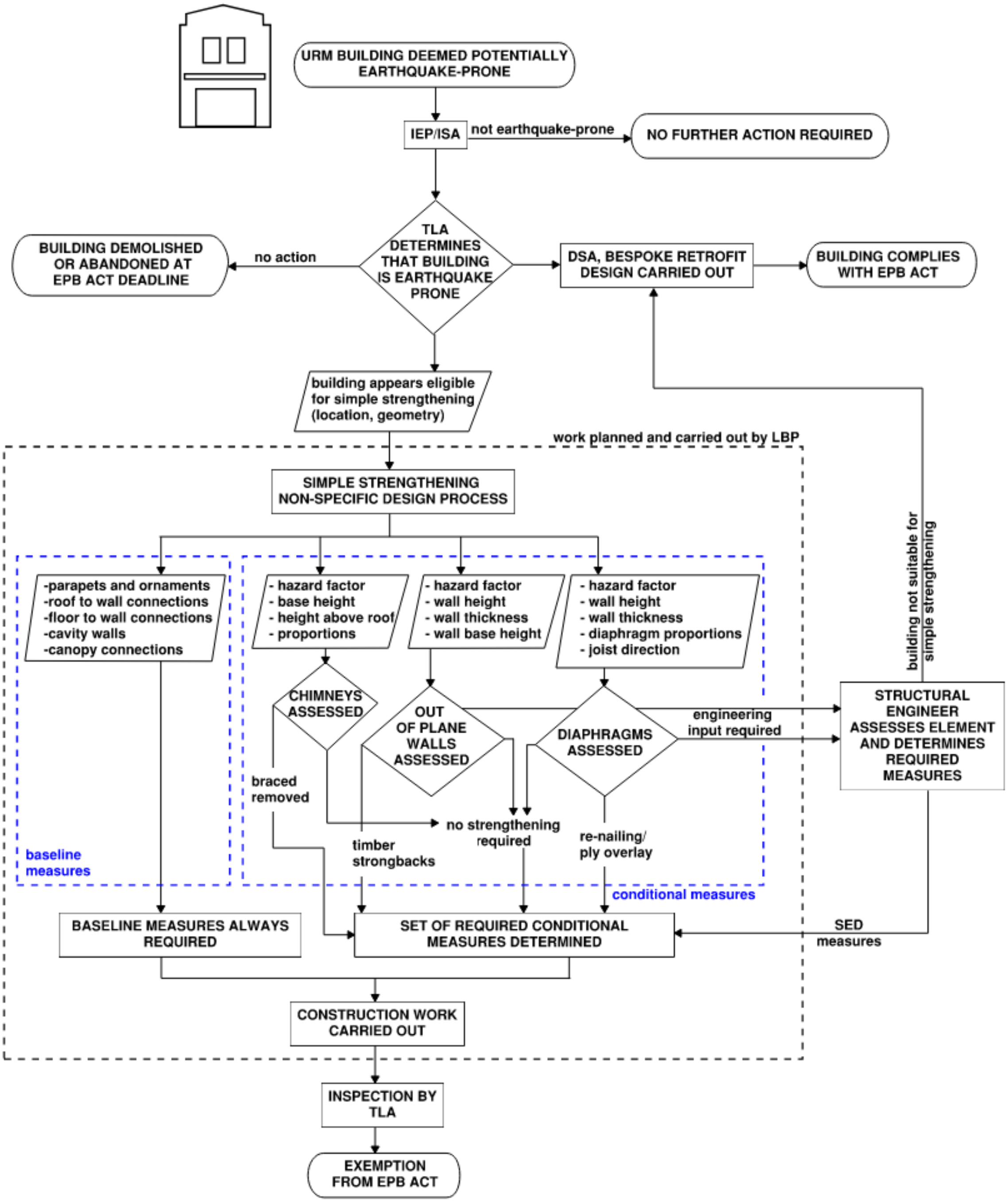
RISK, COSTS AND BENEFITS

The cost to implement the proposed simple strengthening is expected to be lower than the current approach. Reasons include: (a) simple strengthening would not require building-specific assessment and strengthening design; (b) simple strengthening would make use of typical details that have been optimized for buildability and kept consistent over multiple projects; (c) simple strengthening could be managed by building owners and implemented by local tradespeople using readily available building materials. A reduction in cost also appears likely in that simple strengthening is intended generally to be targeted toward primary life-safety issues for URM buildings, such as the tying in of floors to walls, restraint of parapets and restraint of walls out-of-plane (i.e., it is similar to a "Bolts Plus" approach [13]). The costs of a "Bolts Plus" type of intervention, in comparison to "full" strengthening including in-plane wall strengthening, have been investigated in some detail [14-17]. and others. It appears from these studies that cost savings associated with a simpler approach to strengthening could be as high as around 30% - 70% in some cases. However, it must be noted such cost reductions are highly variable and would depend on how the simple strengthening scheme was implemented. Cost-benefit analyses undertaken by Paxton [17] and Cutfield [18] point toward opportunities for significantly increased cost-effectiveness.

LEGAL AND REGULATORY FRAMEWORK UPDATE

This paper proposes an approach whereby eligible buildings that have had the relevant simple strengthening measures applied to them should be exempted from the requirements of the EPB Act. In Tocher and Cutfield [3], the authors noted that a possible mechanism for an exemption is already contained with the EPB Act. Section 401C(b) allows the Executive Council of Parliament to determine "any … characteristics that a building or a part of a building must have for a territorial authority to grant an exemption [from the requirements of the Act] under section 133AN" [19]. Section 401C(b) therefore permits a list of characteristics like those given above to be granted legal force as sorting criteria to define eligible buildings.

Characteristics permitting exemptions are constrained by Regulation 10 of the Building (Specified Systems, Change the Use, and Earthquake-prone Buildings) Regulations 2005 [20]. The regulation uses the terminology *collapse in a moderate earthquake*, as opposed to *ultimate capacity.* As noted above, the structural philosophy of the simple strengthening methodology is to mitigate against collapse. This paper contends that a building which has undergone a well-formulated non-specific strengthening design and received appropriate measures competently installed is unlikely to collapse in a moderate earthquake. Hence, with minor amendments, the presence of simple strengthening attested to by building inspection could serve as grounds for issuing an exemption under Section 133AN of the EPB Act. It is noted that TLAs retain the ability to withdraw exemptions, for example if seismic hazard levels were to change.



[Figure 4] Simple strengthening process flow diagram.

CONCLUSION

This paper presents the outline of a programme (termed *simple strengthening*) for the non-specific design of seismic retrofit for earthquake-prone unreinforced masonry buildings in Aotearoa/New Zealand. The non-specific design process aims to provide sufficient strengthening using standard details to mitigate against the risk of collapse for masonry buildings within certain parameters under a moderate earthquake. The intent of the non-specific design programme is to reduce costs and thereby increase the uptake of seismic strengthening, particularly among buildings located in regional Aotearoa/New Zealand. Under current settings, research has predicted that many of New Zealand's URM buildings in regional centres will be abandoned or demolished rather than retrofitted, leading to a significant loss in social amenity.

The non-specific design process described in this paper divides structural interventions into two categories. The first category contains baseline measures which are to be applied to all buildings using the simple strengthening process. The second category, conditional measures, contains measures which are applied to some buildings, depending on the specific combination of building geometry and seismic hazard. The selection of conditional measures with lookup tables is illustrated. Simple strengthening tables are intended to be easy to apply and designed for use by LBPs. The measures in both categories have been chosen to mitigate against the probable failure modes of URM buildings and significantly reduce the risk of structural collapse.

The paper seeks to present an alternative pathway for owners of URM EPBs through the challenges posed by Aotearoa/New Zealand's seismicity. Previous work has shown that the status quo option for addressing the seismic risk of URMs through the EPB Act is likely to lead to harm for regional communities. By applying non-specific design processes to implement standard-detail retrofit measures, cost reduction and increased strengthening uptake are predicted, with consequent reduction of overall risk. Minor changes to the current regulatory framework are required to create the opportunity for responses to seismic risk targeted to the means and needs of local communities.

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HISTORIC WHARF REPAIR USING MODERN MATERIALS

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Summary: Like many structures of its era, with the decline of the associated industry, Tokomaru Bay Wharf has fallen into disrepair. In recent years, a recognition of the importance of industrial heritage has generated a desire to see it preserved. This has identified the need to preserve both the structure, its history and its links to the community. Following its closure over safety concerns, the Tokomaru Bay Wharf restoration project was initiated to provide a community based solution aiming to not merely address the problem but to do it in a way which provides authentic links to its heritage. With the assistance of researchers from the University of Waikato, a special concrete mix was created which enabled the community workforce to successfully repair of two of the piles at the start of 2021.

Concrete repair, reinforcement corrosion, self-compacting concrete, engineering with communities, wharf restoration, historic structures, conservation

INTRODUCTION

Tokomaru Bay is a small settlement on the East coast of New Zealand's North Island about 90km north of Gisborne. Although not identified as a site of pre historical significance, there is extensive archaeological evidence of pre-colonial inhabitation [1].

In the 19th century the land was settled and a growing agricultural trade developed, initially of flax and grain, then subsequently, when the grazing potential of the area was recognised, wool and meat. A small timber wharf was constructed at Waima on the north end of the bay to provide access for coastal shipping to bring in supplies and export produce. The limited road network at the time made coastal shipping the preferred option for moving goods to external markets.

In the early 20th century a freezing works was constructed at the site and the timber wharf was extended out to 320 m to access deeper water for berthing larger ships. This was well timed, as World War 1 generated a boom in the local industry as all frozen produce was commandeered by the UK government [2]. The establishment of this local industry saw the population grow from a few hundred to several thousand.

In the late 1930s with business thriving a 240m length of the timber wharf was replaced with concrete retaining the timber berthing area at the southern end. Following the Second World War, development of the road network led to an increase in the use of trucks to carry livestock and freight. In the early 1950's these improvements in road transport together with technological advances in freezing technology saw the closure of the freezing works. These changes and a consequent decline in coastal shipping led to the harbour board being dissolved in 1963 [3].

With the decline of the local industry, the population fell and much of the associated infrastructure was left to fall into disrepair. Some of the buildings were adapted as workshops or storage spaces by members of the local community, and until recently, the wharf continued to be used for recreational activities. The importance of the wharf and associated structures in the area was recognised in 1984 when they were given Category 2 Heritage Listing [4]. Renewed interest in the local history and its educational value and a desire to save these iconic structures prompted the formation of the Tokomaru Bay Heritage Trust in 2015. The urgency for action increased following the closure of the wharf in 2017 over safety concerns [5].

THE WHARF

The wharf currently consists of a concrete viaduct extending roughly north-west to south-east for a distance of approximately 240m with the remains of the 80 m timber berthing area at the end. The concrete section is constructed of driven piles with cast headstocks forming bents, the first 28 at 6.1 m centres and most of the remainder at 5.2 m centres. These are connected with cast in situ longitudinal beams and a 3.6 m wide deck, effectively forming a continuous double T section over its length. The 'Government Standard Pattern' piles, an octagonal 'Considère' design [6], are 400 mm across the flats, reinforced with eight 22 mm (⅞") plain steel bars and 5 mm (No.6 gauge) spiral reinforcement [7].

Like many concrete structures in marine environments the wharf exhibits evidence of chloride induced reinforcement corrosion. This is most apparent in the splash zone of the piles where there is extensive spalling of the concrete revealing heavily corroded or missing reinforcement. The longitudinal beams and headstocks exhibit varying degrees of decay with rust staining, cracking and spalling. The concrete on the underside of the deck has spalled over large areas with visible steel loss. However the top of the deck and ‘kerbs’ are in excellent condition, considering the structure's age, with sound surfaces and well defined edges.

Site investigations in recent years have identified that while the deterioration processes are continuing the structure is still in a repairable condition [8]. The main concern highlighted was the integrity of the piles which are unreinforced in the damaged area. Because of this it is considered that there is the potential for a partial or total collapse of the structure if one or more of the piles were to fail in high seas. To address this weakness, two options were proposed, either repairing the piles using a similar methodology to that employed at Tolaga Bay with a concrete jacket being cast around them [9] or replacing them. The latter option would present significant challenges relating to access and was considered unlikely to be cost effective.

HERITAGE VALUE OF THE WHARF

Heritage is a broad concept and includes the natural as was the cultural environment. It reflects and expresses the long process of historical development which, as part of the collective memory of each locality or community, is irreplaceable [10]. Importantly, it cannot be based on fixed criteria with physical heritage needing to be considered within a cultural context [11]. The New Zealand Historic Place Trust relates heritage value to physical factors such as technology and engineering; historic value relating to people, events or patterns; and, cultural values such as community identity and Tangata Whenua [12]. As such, heritage relates to lasting values, which inform us of the past and cultures of our forebears. It is part of the cultural landscape linking the past, present and future, reinforcing community identity and providing a benchmark to measure achievements of the present. It is important that it is understood through connection with the communities who are associated with it [13].

The Tokomaru Bay Wharf has a Category 2 heritage listing which, based on a recent assessment predominantly reflects its historical value [14]. From a purely historical perspective, the Tokomaru Bay Wharf has clear links to New Zealand's rich history of maritime trade and is a landmark to the industrial boom of the early 1900’s. There is little that is recognised to be of scientific, technical, or indigenous cultural significance. By comparison, the Tolaga Bay wharf to the south [9] although of a similar vintage has a broader historical connection and, is also longer, adding to its structural and historical significance.

Having said this, wharves of this type are increasingly uncommon, it has been noted that ‘many New Zealand and Australian heritage wharves are now at risk having been classified unsafe and either being demolished or left to naturally break down’[15]. A review of the Heritage listings shows that Tokomaru and Tolaga Bays are the only locations in New Zealand with surviving wharfs of this type and size. Consequently, this substantially increases the significance of these two remaining sites. In the case of Tokomaru Bay, the wharf and associated structures provide a unique opportunity to preserve something of increasing heritage value. More so, as given the right treatment, it can retain the cultural authenticity, something which has often been lost in attempts to preserve the past elsewhere.

Overall therefore, the wharf has historical significance symbolising a period rather than an event. At both a local and national level, culturally within the community and technologically. It may be considered to represent the fortunes of the people of the Bay, reflecting an era of progress and decline with the potential to be restored and revitalised. Significantly, as one of a few survivors of its era, its importance and relevance will continue to grow.

COMMUNITY ENGAGEMENT

It is important when considering appropriate solutions to any infrastructure issue that the views of the community are taken into consideration [16]. This is more so with cultural or heritage issues. There is much to be gained by taking a community based approach in terms of understanding their needs, visions, desires and positions rather than taking a limited linear approach considering only cost or economic benefit. It should be recognized that there are a multitude of intangible societal benefits which can be gained through projects of this type [11]. They can lead to a rejuvenation of knowledge of a community's history and a restoration of pride in its identity. From discussions with residents it is clear that the Tokomaru Bay Community recognise the cultural heritage of the former industries in the area. As such, the wharf forms part of that community identity, acting as a focal point that provides a tangible link to the past. It is a source of stories that reinforce the memories linking the community to the social, spiritual and cultural significance of the location.

This community has shown its willingness to engage in local projects in the past [17]. The current project, being promoted by the Tokomaru Bay Heritage Trust as a community led organisation, recognises the importance of the history not only at a local level but also as part of New Zealand's industrial evolution. There is widespread support for interventions to retain this built heritage, and develop it in such a way that it will provide educational, recreational and economic benefits [18]. Support is both verbal and material with the community engagement to raise funds to pay for reports, equipment and materials. This overall philosophy aligns with regional and national strategies which recognise the importance of tourism to the economy while identifying that these opportunities are currently underdeveloped. This site has been identified as one of several which could be part of a heritage trail for the region. Recognising the economic value of the site while engaging with the community provides a broader range of options. Restoring access to the historic structures of the town is a first step towards preserving the physical and reinforcing the cultural heritage of this community.

This project can also be seen in a broader context by providing educational opportunities through collaboration with the University of Waikato. This has seen undergraduate engineers gaining a better understanding of the importance of engaging with communities when developing solutions to complex engineering problems. In this case it has reinforced the value of the engagement to the local community; and, provided an additional channel to disseminate information about the project to a wider audience.

RESTORATION OF HISTORIC STRUCTURES

The methodology for repairing concrete damaged by reinforcement corrosion has been well documented [19]. It involves removing damaged concrete, cleaning or replacing reinforcement as required and reinstating missing concrete with an appropriate repair material. Additional passive or active protection of the repairs and surrounding structure is also recommended to reduce the risk of future corrosion issues.

Repair of historic structures is usually carried out using repair techniques developed for modern concrete. From a technical point of view, these materials and methods are generally suitable, however, for conservation purposes, there is a greater need for compatibility with existing materials. In this respect, the performance is often not satisfactory, as the properties of the new materials usually differ from those of the old. Additionally, if consideration is not given to respecting the historic material and heritage values these can be damaged or lost in the process [20]. This does not necessarily mean replacing like with like but should involve attempts to match the key performance properties to ensure repairs are both structurally effective and aesthetically acceptable.

This latter point is often overlooked. It is practically impossible to obtain an exact match to the original concrete even if a repair is well executed with a matching surface texture and colour. Even with similar materials, the effects of weathering and time can lead to visible changes. Repair materials are generally designed to have low permeability which creates visible differences compared to the substrate as the surface moisture conditions change. These differences can, in some instances, be reduced with surface treatments but they can't always guarantee a uniform finish.

Repair of historic structure must therefore be based around developing appropriate strategies which: adopt good conservation practice; use minimum amounts of intervention [21]; retain and reveal heritage values; and, retain authenticity [13] The choice between traditional and innovative techniques should be weighed up on a case-by-case basis and preference given to those that are least invasive and most compatible with heritage values, bearing in mind safety and durability requirements [11]. Depending on the level of deterioration and the functional requirements the varying degrees of interventions can be summarised as follows [13]:

1. Preservation, through stabilisation, maintenance, or repair;
2. Restoration, through reassembly, reinstatement, or removal;
3. Reconstruction; and,
4. Adaptation.

Any intervention which reduces or compromises cultural heritage value is undesirable and should be avoided. The lowest level of intervention should aim to ensure the long-term survival and the continuation of the cultural heritage value of a site or object. Repair of a technically higher standard than that achieved with the existing materials or construction practices may be justified if the stability or life expectancy of the site or material is increased, the new material is compatible with the old, and the cultural heritage value is not diminished.

With increasing levels of intervention, restoration is appropriate, which typically involves reassembly and reinstatement, and may involve the removal of accretions that detract from the cultural heritage value. The term 'Restoration' used in the title of this paper and in the section heading is based on a dictionary definition: '...the act or process of returning something to its original condition by repairing it, cleaning it, etc.' [22]. The ICOMOS NZ Charter defines this as reconstruction [13].

Reconstruction is a higher level intervention, distinguished from restoration by the introduction of new material to replace lost material. This is appropriate to ensure structural integrity and if carried out in a way which does not destroy the heritage value. A choice of technique must be determined on a case-by-case basis with preference for methods which are most compatible with heritage and conservation practice. They must also reflect safety and durability requirements which are not always easy to determine. An observational method may be appropriate to assess the relative safety benefits of interventions, starting with a minimum level, with adoption of supplementary or corrective measures if required [11]. This must however be done in a sensitive manner to avoid the 'patchwork quilt' of different repairs sometimes seen in old structures [15]. Methods and materials should be assessed for their reversibility and re-treatability; reversibility allows for the repairs to be 'undone' in the future if they are subsequently considered to be inappropriate or unsuitable; re-treatability allows for further treatments to be applied in the future [20].

When deciding on appropriate interventions, another factor which must be considered is service life. For new structures, service life is part of the design considerations; for historic structures, which may have already exceeded their design service life, this will need to be determined based on the anticipated use of the structure in the future. From the perspective of cultural heritage, whatever process is adopted, it should take into account the continuing uses and the links those uses have to the heritage value. For Tokomaru Bay Wharf, its original use can be retained, but at different levels. This may reflect its community use in recent times (since the closure of the works) and also the potential to develop tourist interest which will be enhanced once the wharf is reopened to the public.

In this instance, there may also be good arguments for what is termed adaptive reuse - 'Finding ways to move a building into the present… while preserving the links to the past that make it so special' [23]. As part of a conservation plan this can identify new uses for a heritage structure which still reflect its original use but also demonstrate an evolution of its use.

A variation to this approach has been proposed for Tokomaru Bay based on the Japanese philosophies of Wabi-Sabi, Ma and In-Ei, which would see the structures in the area stabilised to prevent further deterioration and collapse, preserving them more or less as they are [24]. The author argues that restoration to original condition is not viable for historic buildings whose original programme is no longer relevant. In addition, complete restoration destroys qualities of the decay which form part of the history. Without this additional consideration there is no ability to connect to the story associated with the abandonment and ruin of the site. There is also reason to suggest that restoration should aim to capture both the character of buildings in their heyday and elements of their decline and deterioration. Taking this view further see justification for modern additions on the buildings, reflecting the current forms and revival of the site, enabling visitors to experience the history of the area in a much broader sense.

REPAIR METHODOLOGY

In light of the wharf condition and the community desire for action a proposal was put forward in 2019 to carry out trial repairs to four of the piles on the wharf. The proposal was to adopt a similar methodology to the repairs carried out previously at Tolaga Bay involving strengthening of the piles with a concrete jacket. Unfortunately, the method adopted is a compromise between conservation and conservatism. This has produced a solution which breaks many of the fundamental criteria for heritage conservation. On the one hand, there is a genuine need for action to preserve the structure for future generations while on the other there is the need to apply current design standards. Unfortunately, regardless of cultural value, interventions must be in proportion to safety objectives [11]. Although 'adding' to the structural form lacks the authenticity of the original, it was felt that this was the best compromise to see progress with the available resources at the time. It may also be argued that carrying out the repairs still adds to the cultural heritage value of the site by adopting a process which allows work to be done by members of the community.

The proposal recommended the use of glass fibre reinforced polymer (GFRP) reinforcement in place of conventional steel to avoid future corrosion issues. GFRP has proven durability performance in marine environments being corrosion resistant. It has higher tensile strength than steel while being much lighter (about one quarter of the weight) making it cheaper and easier to transport. It is cost effective when compared to stainless steel and it was also available from a local manufacturer [25].

The proposal included options to use either a pre-packaged repair material or cast in situ concrete. A site batched concrete was selected as the most cost effective option for this application. The restricted access to the piles presented challenges for placing the concrete and ensuring it was adequately compacted. Self-compacting concrete (SCC) was identified as a solution to both of these problems allowing the repair material to be poured into a mould through a tube with no external vibration needed to compact it.

Development of this material was the focus of a University of Waikato research project. The mix design for the SCC was developed from one reported previously [26]. SCC mixes typically have higher fines (cement, cement replacements or mineral powders) contents than conventional concrete. This, in combination with high performance superplasticizers, is necessary to achieve the desired self-compacting flow properties. The New Zealand Standard for concrete structures [27], requires a minimum binder content of 450 kg/m^3 for reinforced concrete in marine environments with the binder consisting of Portland cement and a supplementary cementitious material - fly ash, micro silica, or ground blast furnace slag. Fly ash was readily available and was known to give good flow properties so was chosen for this application. The Standard also specifies a maximum water to cement ratio of 0.45 and minimum strength grade of 40 MPa. These latter criteria are readily achievable with SCC mixes due to the high binder content and superplasticiser.

Trial mixes using local aggregates were carried out in the University of Waikato laboratories which demonstrated that the mix design had good flow and strength properties, with 28 day strengths in excess of 50 MPa. Field trials were conducted using a quarter size mock-up of the repair to confirm the SCC worked in this repair application. This effectively demonstrated the suitability of the proposed material.

To prepare for the repairs, deteriorated concrete and reinforcement were removed using mechanical methods. Exposure of the steel in the lower part of the piles showed it to be in excellent condition with little sign of corrosion. This is not uncommon in marine structural elements below the splash zone. While settled weather conditions were desirable for this preparation work to allow access to the piles at low tide, they were essential for the subsequent repair application.

The GFRP cages were prefabricated in two halves using preformed five sided links at 150 mm centres. Once fine weather was forecast, the cages were lowered into place, the two halves fitted either side of the prepared pile, then tied together with overlapping links. The top of the completed cage was connected to stainless steel starter bars bolted to the headstock, while the bottom overlapped the undamaged pile section. The whole cage was secured with short lengths of GFRP bar fixed into the substrate concrete. Once the cages were fixed, the mould was assembled around the pile in preparation for the concrete pour. As this process took at least one day, the concrete was placed the following day with mixing and pouring as a continuous process until the mould was filled. The mould was left in place for seven days to protect the concrete from wave action. After the mould was stripped the concrete was wrapped in wet burlap and plastic to aid with the curing.

The process was repeated on the second pile of the bent two weeks later. The outcome of the trials showed that the materials and methods were effective. The work was carried out by a small team of local volunteers who, with a small amount of training, were able to become competent with a range of processes including: cutting back and preparing the old concrete; fixing reinforcement; installing the mould; then, mixing and placing the new concrete.

Taking a longer term view in addition to preserving the structure, there is also a desire to retain the physical appearance of the wharf structure. The discovery that the reinforcement in the lower part of the piles is sound provides an opportunity to do this. With this knowledge it is possible that a repair design using GFRP rods connected directly to the existing rebar in the lower part of the pile can be developed. Replacement concrete can then be cast to the original pile profile while still providing adequate cover.

CONCLUSIONS

The historic wharf at Tokomaru Bay is recognised as a unique community asset which, as one of few survivors of a bygone age, deserves recognition and preservation. Restoration of historic structures is not without its challenges and sometimes it is necessary to find a compromise between conservation and conservatism, recognising that solutions need to be both safe and sensitive to the heritage values of the site. Engagement with the Tokomaru Bay community identified a desire to save the wharf both for its historical importance and to see it developed for education and cultural tourism for future generations. The connection to this history has resulted in enthusiastic community engagement raising funds to pay for reports, equipment and materials with a small and dedicated local workforce providing the project management and labour. The process to save it has culminated in trial repairs to two of the supporting piles using novel materials and methods. These trials demonstrated that there is opportunity for this project to further develop the cultural heritage of the structure and the local area. The viability of the materials and method have been demonstrated and repair of a second bent is planned for the end of 2021. To enable a more authentic solution further research work has been proposed by the University of Waikato.

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3D LASER SCANNING - DIGITALLY PRESERVING THE PAST, TO MAKE READY FOR THE FUTURE

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Summary: Knowledge of the location, size and shape of a historic structure or site is fundamental to any project related to the conservation or adaptation of cultural heritage. Simple photographs and 2D drawings are quickly being replaced with rich, photorealistic 3D data for analysis & visualization, which serve as an enduring digital record of the structure or site. This paper will provide guidance on the use of 3D laser scanning across the heritage sector and should assist cultural heritage professionals making the best possible use of this now highly developed technology. Local New Zealand examples will be used to demonstrate the results achievable.

INTRODUCTION

Traditionally, heritage structures or sites have been documented with drawn, written, and photographic records. Due to the often-complex geometry of historic structures, it has been a challenge to capture and document the true size, shape and relationship to adjacent features using basic measurement equipment such as a simple tape measure or even more advanced total stations. While 2D plans, elevations and sections are convenient to include in a written report, these simplifications of reality often fail to tell the full story.

Recent technological developments in laser scanning and imagery systems and their supporting software have greatly improved their ease of use, speed, accuracy, portability and affordability. There has also been a proliferation of effective methods of sharing the rich data produced, such as web-based 3D point cloud and mesh viewers. These developments have enabled mass data collection and delivery mechanisms that not only provide intricate detail on the heritage subject as the basis for conservation analysis, but have the potential to increase public engagement, awareness and knowledge of our heritage structures.

Although the collection, processing and presentation of point cloud data has become more manageable than ever, the dizzying array of laser scanners and supporting workflows, all with their own strengths and weaknesses, mean that some prior knowledge is required when specifying or commissioning work to be done. While 3D laser scanning has been widely adopted in New Zealand in industries such as industrial, architectural, civil surveying, urban topography, mining and even the movie industry, the heritage engineering sector in New Zealand has only seen limited uptake of the technology. It is my opinion that this is mainly due to a lack of understanding of how best to specify or commission such a survey so that an appropriate, cost-effective outcome is achieved.

This paper, which draws heavily from an excellent resource titled "Historic England 2018 *3D Laser Scanning for Heritage Advice and Guidance on the Use of Laser Scanning in Archaeology and* Architecture. Swindon, Historic England" [1], aims to provide updated guidance on the utilisation or commissioning of three-dimensional (3D) laser scanning across the heritage sector to achieve the best possible outcomes.

Local New Zealand examples will be used to demonstrate the results achievable and the digital assets that can be delivered.

BACKGROUND

The importance of accurate records of historic structures

Heritage New Zealand, through *HNZ – Archaeological Guidelines series No. 1 Investigation and Recording of buildings and standing structures – Survey levels 1-3* states that the "importance of systematically examining buildings and standing structures to provide information about the past has been increasingly recognised for providing a platform for improving heritage outcomes [2]. *ICOMOS' Principles for the Recording of Monuments, Groups of Buildings and Sites (1996)* provides reasons for recording that include understanding the values and evolution of cultural heritage; promoting interest and involvement in the preservation of heritage; permitting the informed management and control of any change to heritage; and ensuring that the maintenance of heritage is sensitive to its physical nature and its significance.

Buildings and structures do not exist in isolation, and it is therefore important that their relationship to the surroundings is also captured [2].

The Investigative process for heritage sites

The process of investigating a heritage site can be divided into three stages: evaluation, recording and analysis [1]. 3D laser scanning can add significant value throughout this process.

During the initial evaluation stage, where the potential value of a building or structure is identified and assessed, a site visit is normally required by a person skilled in the identification and assessment of buildings. The rich, detailed digital replica of the site captured by a 3D laser scanner can capture the entire visible surroundings, potentially allowing a range of experts and stakeholders to inspect a place within its landscape setting all from the comfort of their office. While not removing the need for a site visit, the digital replica could make it possible to bring the right experts in to the decision-making process without incurring significant travel time and cost. Recording involves the capture of information about composition of a building or structure (HNZ). The site would, most commonly, be documented with a combination of individual hand measurements and photographs. This piecemeal method risks that not all features of interest are captured and that repeat site visits may be required. Discrete measurements are also error prone and the location and orientation of the disconnected photographs captured are open to misinterpretation.

Measured drawings have traditionally been required to be produced as plans, elevations and sections in order to detail the structure or building and convey accurate visual information about its appearance. Such documentation dilutes the complexity of the structure and requires knowledge and experience to be able to correctly interpret the data, especially in lieu of a site visit. Much of this experience is becoming difficult to procure, yet the decisions that need to be made based on the data grow more complex and demanding.

The capture of a complete digital replica of the site by 3D laser scanning allows for analysis of the data by a wider range of specialists who are able to more intuitively understand the information as it is presented in an easily understood 3D, photo-realistic representation. The chance of misinterpretation is minimised.

APPLICATIONS FOR LASER SCANNING IN HERITAGE PROJECTS

Laser scanning has a wide range of uses in heritage projects. The detailed record of the site allows accurate measurements to be extracted, providing the basis for a wide range of applications, some of which are summarised below:

- A comprehensive archivable record for a structure or site, and context in its surroundings, which may be lost or changed due to works or a disaster (fire, earthquake, flood etc.)
- A detailed record of the subject prior to any intrusive works beginning and as a basis for 3D redesign work. This could include building code compliance, new fit out, extensions/modification, and the improvement of access.
- Structural or condition monitoring where the site is subject to subsidence or erosion
- As the basis for ‘reality models’, video fly throughs and illustrations which can be published online for increasing awareness, accessibility and engagement. Increased virtual and physical tourism.
- As the basis for producing a scaled model for display (e.g. 3D printing)

[Figure 1] A Leica RTC360 Laser Scanner capturing a heritage building

[Figure 2] A survey-grade Leica P40 Laser Scanning capturing a historic building facade

COLLECTION AND UTILISATION OF LASER SCANNING DATA

Who can use this technology and how simply and accessible is it in practice? Historically, the digitisation of the physical world has been the exclusive domain of trained surveyors. Surveyors are trained to apply instrumentation and methods appropriate to the level of accuracy required for the end use of the survey deliverables. With the recent proliferation of user-friendly 'reality capture' devices at affordable price points, including cloud-to-cloud based laser scanners, the capture of 3D data has been opened to a wider range of users.

While 3D laser scanners have become incredibly easy to operate, this hasn't completely removed the need for survey knowhow. For example, technical skill is required to control the accumulation of errors, especially through larger projects, and to determine and label the accuracy of the finalised point clouds, which normally involves the use of independent measurement techniques. What is a point cloud?

The raw data captured by a 3D laser scanner or Lidar (light detection and ranging) is known as a 'point cloud'. Each point in this 'cloud' has a X, Y and Z geometric coordinate representing a single point on every visible surface of the structure or scene of interest. When combined with imagery systems, which are often incorporated into modern 3D laser scanners, colour information can be added to these coordinated points providing valuable real-world context.

3D laser scanners can capture millions of 3-dimensional coordinated points every second, allowing users to quickly build a powerful three-dimensional, coloured digital replica of a subject.

Laser scanners operate from a sequence of tripod-mounted 'static' scan locations or from a mobile or handheld platform. Static scans are located such that after the individual scans (point clouds) are brought together in a process called registration, a complete set of scan data is produced. Mobile scanners are moved through the scene in a manner that captures all the required details as the scanners field of view changes.

How can I utilise a point cloud?

By their very nature, point clouds are large, heavy files. Historically, this has presented a barrier to their adoption as expensive computer hardware and software has been required to store, visualise, navigate and extract measurements from these files. This meant that it was frequently necessary for the point cloud to be modelled into simplified geometric objects for delivery to end consumers of the data, adding significant expense to the workflow.

The rapid development of faster and more powerful computers at affordable prices together with the rise of advanced software solutions for more efficiently storing and rendering point clouds, means that the sharing and consumption of point clouds has become more accessible to a wider range of users.

There are a range of methods used to work with and extract precise measurements from point clouds including many license-free point cloud viewers, which operate either through a desktop application or even via a standard web browser.

It is also possible to extract other digital deliverables from point clouds including, but not limited to:

- 3D reality meshes with photorealistic texturing
- 3D terrain or surface models
- 3D Building Information Models (BIM)
- 2D Drawings such as topographical plans, cross-sections, or profiles

For more information on these deliverables, see Appendix B.

SPECIFYING AND COMMISIONING A SURVEY

To ensure a successful outcome, there are some important considerations to make before beginning your own point cloud survey or commissioning a surveyor to do the work for you. The intended end use, the scope, and the required resolution and accuracy of the point cloud have large implications on the selection of equipment and methods and, subsequently, on the time and cost of the survey.

[Table 1] The key considerations when specifying or commissioning a point cloud survey

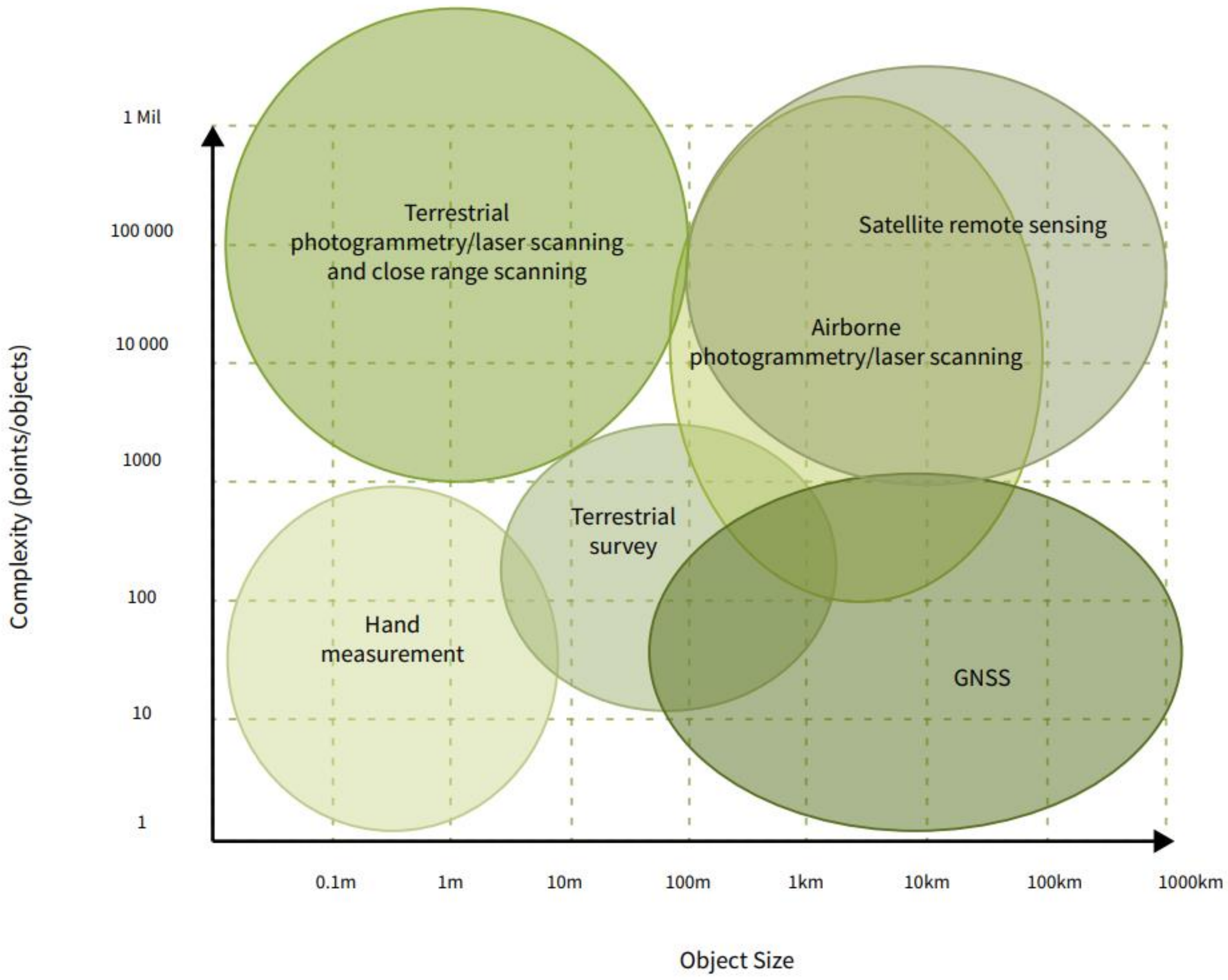
Purpose	Having a clear description of the purpose or end use of the point cloud helps in the selection of the equipment and methodology used.
	Why is the data needed?
	• Visualisation for conceptual design, master planning or conservation purposes
	• Accurate 3D measurement (checking site records)
	• Basis for detailed design or fabrication
	• 2D Extractions (Floor plans, profiles, cross-sections)
	• 3D BM modelling
	How will the data be used?
	• In which software (Free Viewer, CAD Software, Modelling Software)
	• Does the end-user of the data have capable PC hardware to use it?
	How will the data be delivered?
	• Raw point cloud (unified or structured)
	  ○ .LGS, .RCP, .E57, ASCII
	• Models, Plans, Elevations
	  ○ Revit, IFC, DWG, DXF
	• Cloud sharing platforms or physical hard drives?

Scope	A clear definition of the scope of the area to be captured. • Extents of survey and a well-defined list of structures and elements to be included in the survey. • e.g. structural features, roof areas, facades, ceiling spaces, surrounding street scene/adjacent buildings, services, architectural detailing

Accuracy and Resolution	The level of resolution (or point cloud density) and accuracy required has a significant impact on the cost of the point cloud as it determines both the equipment and methodology selected and the rigorousness in which they are applied and verified. A general rule of thumb is that the point density or resolution should be more than twice as dense the size the smallest feature to be identified. The accuracy should, at the very least, be equivalent to the resolution [1]. Depending on the environment, it's relatively easy to achieve a point cloud where the precision (or repeatability) of measurements across short distances is very good (within a few millimetres) and the accuracy across the expanse of the project is within 30 – 50mm. To achieve a higher level of accuracy across a larger site (projects of 20 or more scans) a significant level of survey rigour is required to achieve accuracies at the sub 5mm level, which involves more time-consuming field and office processes, adding significant cost.
Georeferencing	The use of survey control on a project serves two important purposes. The first is to provide a well distributed network of accurate points to aid or check the registration of the scans into a single, unified point cloud. It is important to be aware that errors will accumulate with each join between setups. While this may be insignificant on smaller scale project, on larger projects where dozens (or even hundreds) of setups are captured, this accumulation of error may be significant. The strategic placement of targets, which are visible in the point cloud, and measurement of these targets with an independent measurement technique such as a Total Station or a GNSS instrument (and possibly a precise level) allows for the accumulation of errors to be checked and controlled. The selection of a suitable measurement technique will depend on the accuracy requirements of the project. The second purpose of survey control is to place the point cloud in terms of a local coordinate system and height reference datum. This may be necessary if the point cloud data is to be combined with spatial data from other sources or if return site visits are planned for monitoring of change over time or for the set-out of new designs. Normally the establishment of a control network with an independent measurement technique adds significant expense to a project, but makes the final point cloud fit for many more purposes downstream.

SELECTING A METHOD OF SURVEY

Once the end purpose of the survey is clear and the accuracy and resolution requirements have been determined, the size of an object or scene and its accessibility will guide the selection of the most appropriate method of survey. Figure 1 attempts to identify and differentiate between the available techniques to guide the user towards an appropriate selection.



[Figure 3] Survey techniques defined by object complexity (points captured) and size, derived from Boehler et al (2001)

For complex projects, laser scanning is clearly the best option. 3D Laser Scanning, often complemented with control from traditional survey methods for larger scale objects is most suitable for the most complex of subjects across varying scales, whether they are carried out by tripod based static scanners or mobile laser scanners.

If it is determined that the project suits a laser scanner, the next step is to identify the best device and capture technique. There are a wide range of laser scanners available that operate on differing principles, in different environments and with different levels of precision and accuracy. There is no one-size-fits-all instrument, so it is important to select the right tool for the job. Appendix A explains in detail how to select an appropriate instrument.

VERIFIYING THE RESULTS

While it's simple to produce a 3D point cloud that *looks* accurate, rigorous quality control and data validation procedures are essential to be able to *prove* the point cloud meets the accuracy requirements of a project. This is the area of expertise of a surveyor. A combination of the below techniques can be used:

- Assessment of the cloud-cloud error estimates provided by the registration software. This can include estimations of the Root Mean Square (RMS) quality of the cloud alignment, overlap and strength

- Assessment of the mis-closure in the data made by linking overlapping scans in closed loops provides a good indication of the accumulation and adjustment of any error when the final station in a chain is looped back to first station.
- Visual inspection of sections taken through the data in X, Y & Z Axes with particular attention to lamination of surfaces (offsets), rotation of scans and varying wall thicknesses
- The placement of targets around the extents of a scene using a visible horizontal laser provides a simple way of confirming the level plane of a point cloud
- The strategic placement of a control network, as discussed previously, provides the only independent way of verifying the overall 3D accuracy of a point cloud

NEW ZEALAND CASE STUDIES

Lyttleton Tug

[Figure 4] Final unified point cloud of the Tug Lyttelton as scanned by the Leica RTC360

This historic steam tug is maintained and operated by the Tug Lyttelton Preservation Society, a non-profit organisation who run popular scenic cruises across Lyttelton harbour. Tug Lyttelton was built in Glasgow, operated in Lyttelton between 1907 and 1973 and holds a special place in the hearts of maritime enthusiasts across New Zealand.

Objectives

The vessel was berthed at Lyttelton Port of Christchurch and surveyed and maintained at Stark Bros dry dock during the winter of 2020. It was while she was in dry dock that our team had the ideal opportunity to laser scan the whole vessel, inside and out.

This historic steam tug has a very complex structure, particularly below deck, with a labyrinth of narrow passageways and bulkheads connecting many complicated confined spaces. It presented a good challenge for acquisition of an accurate and detailed point cloud and complimentary spherical imagery.

The aim of the exercise was to produce some visually engaging 3D visualisations of the Tug, inside and out, which could be used to raise the general awareness of the Tug and generate a digital archive of this important heritage object.

Methods

As the main expected use of the data was high resolution visualisation, the point cloud needed to be highly precise (low-noise), dense (<2mm to pick up small details) and textured with colour. The absolute accuracy of the point cloud from one end of the tug to the other was not a high priority but a tight registration was required for visualising cross sections through and along the length of the structure. As the tug is a moveable object, geo-referencing was not required.

The environment, which was very constrained thanks to the enclosed dry dock outside and the small, closed spaces inside, leant itself to “cloud-to-cloud” registration (a technique that requires a significant percentage of overlapping scan data) both in terms of efficiency and accuracy. Targets were only used for difficult transitions between spaces such as hatches into chambers where it was difficult to capture overlapping clouds.

The Leica RTC360 scanner was selected as the tool for the job as it’s speed (360° scan in as little as 26s and panoramic imagery in 60s) gave us the luxury to capture more than enough overlapping data to create a comprehensive and robust registered point cloud while the instruments’ ability to capture HDR imagery provides an evenly coloured point cloud. The RTC360 captures very low-noise data (sub-millimetre range noise) which provides crisp, high-quality scans that are rich in detail. In this case we captured almost 1 billion points over 120 scans.

[Figure 5] An example of the 5K HDR panoramic images captured by the RTC360. The red spheres show a sub-selection of the setup locations used to capture the point cloud and panoramic imagery.

Results

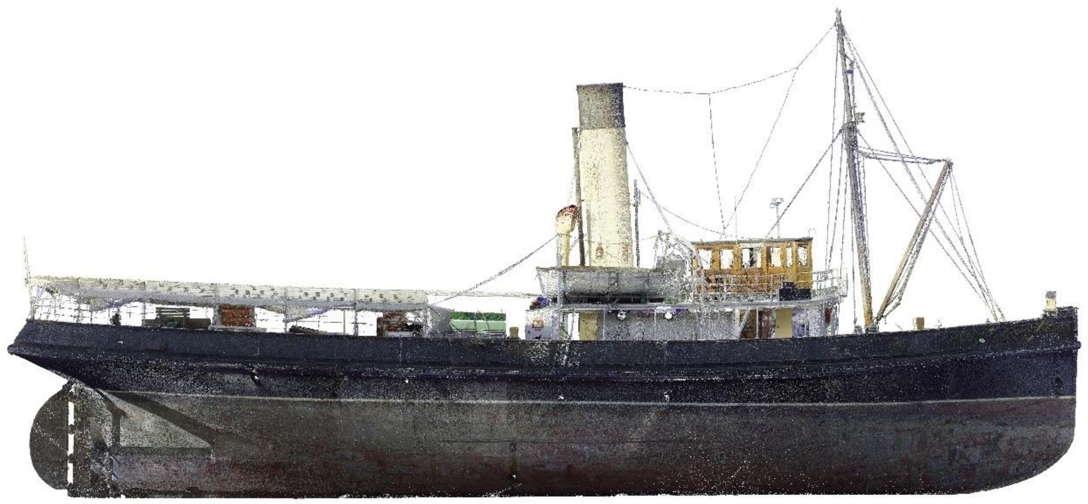
The low-noise scan data and high-resolution HDR imagery captured by the Leica RTC360 delivered crisp, high-quality point clouds that are rich in detail and can be used for a range of additional deliverables to support future engineering and design.

The relative accuracy of the point cloud was verified with a combination of the quality control procedures:

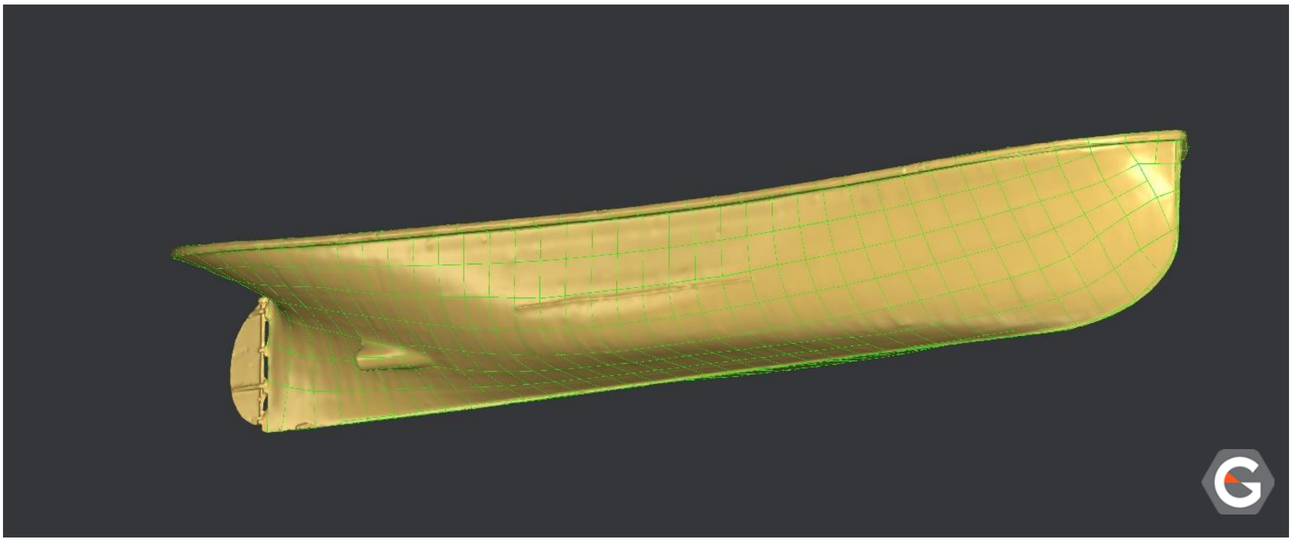
- Assessment of the cloud-cloud error estimates
- Assessment of the closures of loops in cloud-to-cloud links (e.g. around the outside, in and out of interior spaces)
- Visual inspection of slices through the X, Y & Z Axis with particular attention to lamination of surfaces, rotation of sub-bundles of scans and varying wall thicknesses

The point cloud was then further processed in Leica Cyclone 3DR software for the creation of final deliverables including:

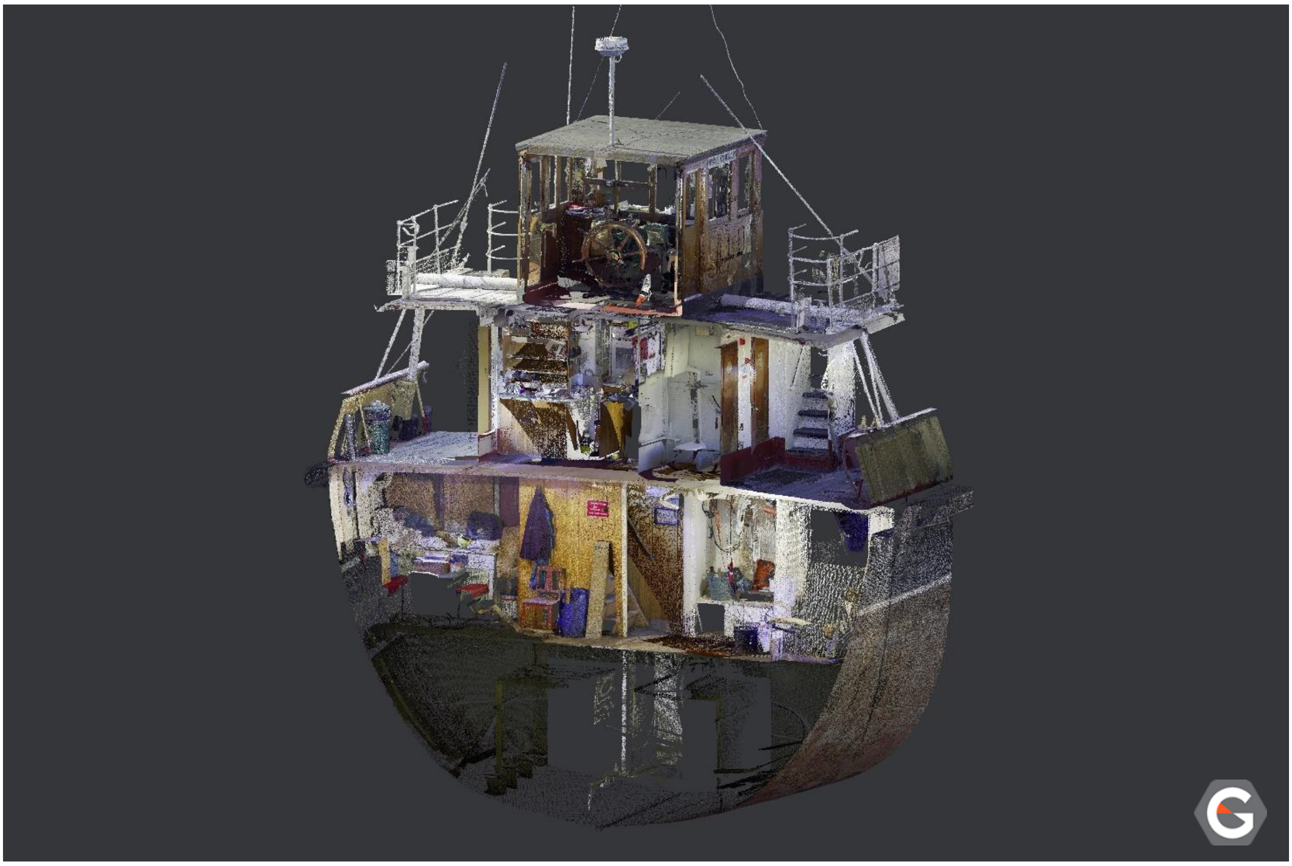
- A highly detailed, cleaned, coloured point cloud
- Orthoimages of the point cloud from different perspectives
- A lightweight complex mesh of the outer hull
- A reverse engineered CAD-model of the outer hull, which could be used to construct a scale model of the tug



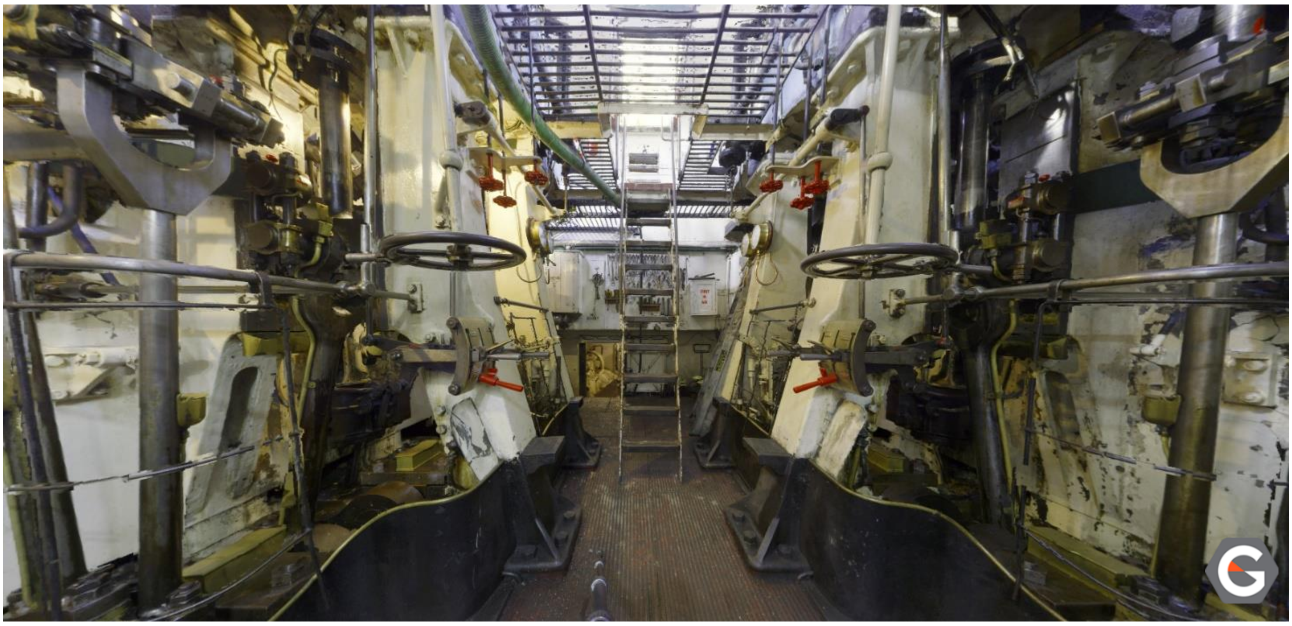
[Figure 6] An orthographic image of the unified point cloud



[Figure 7] A reverse engineered CAD surface extracted from the point cloud in Cyclone 3DR software



[Figure 8] A slice of the point cloud showing the interior spaces captured



[Figure 9] A panoramic image captured with the RTC360 down in the engine room

[Table 2] Effort Involved for Tug Lyttleton Case Study

Task	Time taken
Planning	0.5 day
Field data capture	1 day
Process a point cloud	1 day
Reverse Engineer CAD Surface	0.5 day
Total	3 workdays

Outcomes

The Tug Lyttleton still operates fully booked tours on Lyttleton harbour after 107 years of service. The tug's working future is hopeful, and its digital future is now assured.

The result of this project is an accurate 3D digital copy of the Tug Lyttelton historic vessel that was presented to Society President, Roger Ellery at the Tug Lyttelton Preservation Society's AGM in September 2020. The results are not only visually engaging, but also an invaluable accurate 3D digital record of an important part of New Zealand's heritage. The Preservation Society plans to use the visuals as part of their fundraising efforts to keep this magnificent vessel in operation for years to come.

Christchurch Arts Centre (Project completed by Eliot Sinclair & Partners)

Objectives

To generate an accurate point cloud of a stripped out historic building which would be used by structural engineers, architects and also contractors (including stone masons, for example) throughout the project to re-purpose this historic building into a boutique hotel.

Methodology

As survey grade accuracy was required, the Leica P40 Laser Scanner was selected for the job. The P40's top end range and angular accuracy paired with low range noise and survey-grade dual-axis compensation are suited to projects where the highest accuracy is required.

A combination of cloud-to-cloud and target-based registration processes were used, and the final accuracy of the point cloud was verified with a control network of coordinated targets measured with an independent measurement technique (a combination of Total Station and Precise Levelling) as well as the inspection of vertical and horizontal sections through the data. The control network was also used to georeferenced the data in term of the project's coordinate system.

Results

A point cloud was delivered, which covered all four floors of the structure including the roof cavity, which was not normally accessible due to multiple health and safety hazards. A final accuracy of +/- 4mm over the entire extents of the point cloud was achieved, meaning that the data could be used for detailed architectural and structural design and also relied upon for clash detection (the virtual assessment of the interaction between existing elements and new design features or services).

[Figure 10] A sample of the survey-accurate point cloud captured (Courtesy of Eliot Sinclair)

[Table 4] Effort Involved for Christchurch Arts Centre Case Study

Task	Time taken
Planning	4 days
Field data capture	1.5 days
Control survey	1 day
Process a point cloud	5 days
Total	11.5 workdays

Outcomes

The point cloud and a point cloud viewer have been used regularly for over 4 years by structural engineers, architects, mechanical engineers and more recently by construction companies. As the project is still ongoing, we can expect the data will continue to be used for some time to come.

NG Building, Christchurch (Project completed by Woods & Global Survey)

Located at 212 Madras Street, the NG Building is the last of the majestic Victorian and Edwardian style warehouses which characterised Christchurch in the early 1900s. Completed as a warehouse in 1905, incorporating New Zealand timber and stone, it is not only of important historical significance, but also is of considerable cultural and economic value to the central city.

At beginning of 2021 the future of the building was uncertain. The NG building sits on land intended for the multi-use arena project and, to the shock of the owners and tenants, new designs were released that required the building to be demolished. The Crown began the process of compulsory acquisition of the NG building. The owners, determined to save the building, didn't give up and eventually signed a deal with Government which involves moving the entire NG building down the road to a new site behind the Cardboard cathedral, opposite the CTV Park.

Objectives

The ambitious plan to move the building, involves cutting through the basement just below ground floor, raising the building, then moving it to the new sight on tracks. It is then to be lowered onto a new purpose-built basement. As there is a level of risk that the building is damaged during relocation, both Woods and Global Survey saw this as a great opportunity to put their reality capture tools to the test and capture the building in its entirety in its original location.

Methodology

The RTC360 was chosen once again, based on its speed and low noise data, which is perfectly suited for producing high quality 3D renderings.

The building was scanned inside and out. Cloud-to-cloud registration was used for the majority of the registration and was complemented with targets for checks outside. Scans were captured in several open doors and windows, allowing several loops to be closed to the ensure confidence in the final registration.

[Figure 11] The author looking on as the Leica RTC360 scans the outside of the NG Building (Photo Credit: Maksym Khovalko)

A DJI Phantom 4 RTK drone was also flown over the building to capture the roof areas not visible from the ground and the datasets were combined using common targets.

Results

The highly detailed point cloud was produced. The relative accuracy of the point cloud was verified with a combination of the quality control procedures:

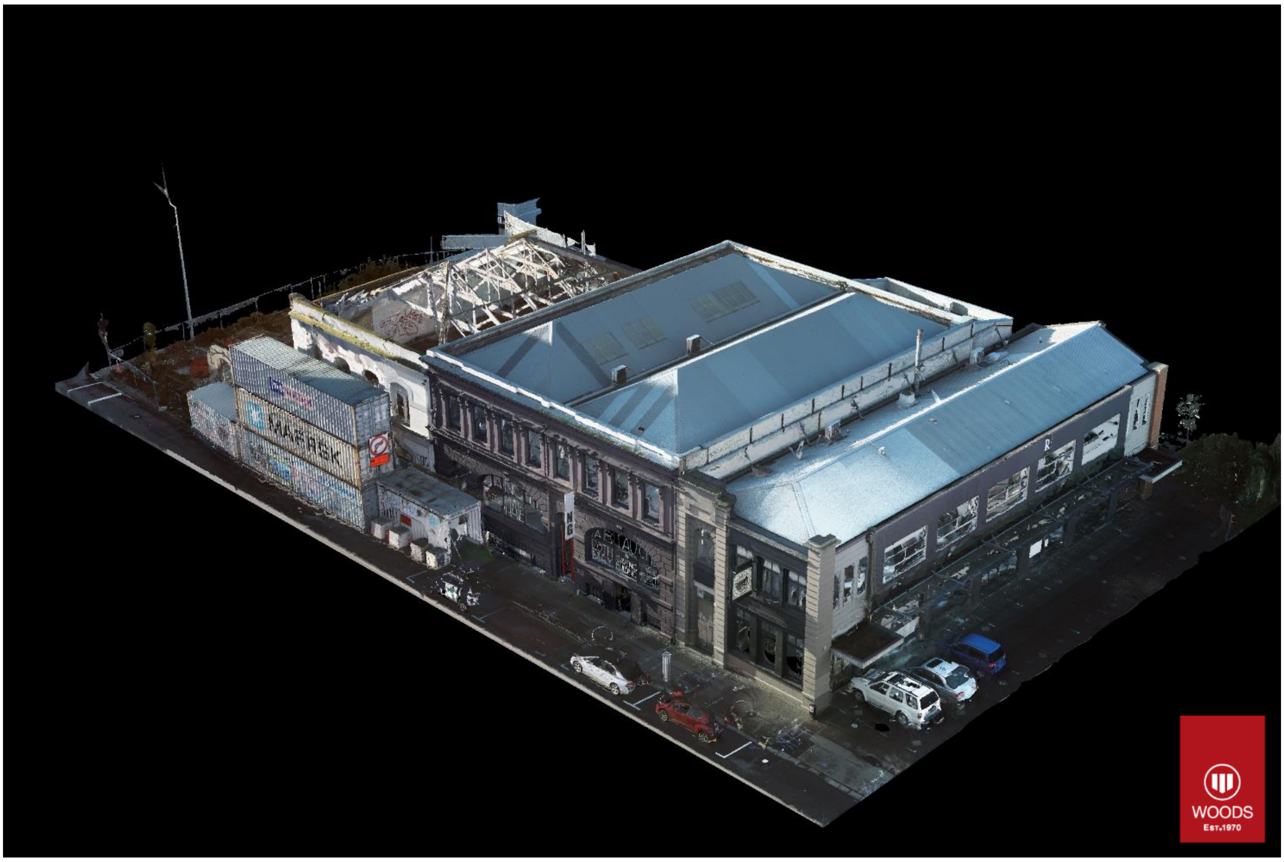
- Assessment of the cloud-cloud error estimates
- Assessment of the closures of loops in cloud-to-cloud links (e.g. around the outside, in and out of interior spaces)
- Rigorous visual inspection of slices through the X, Y & Z Axis with particular attention to lamination of surfaces, rotation of sub-bundles of scans and varying wall thicknesses

The imagery captured by a combination of drone and handheld photography was processed together with the point cloud to produce a hybrid model.

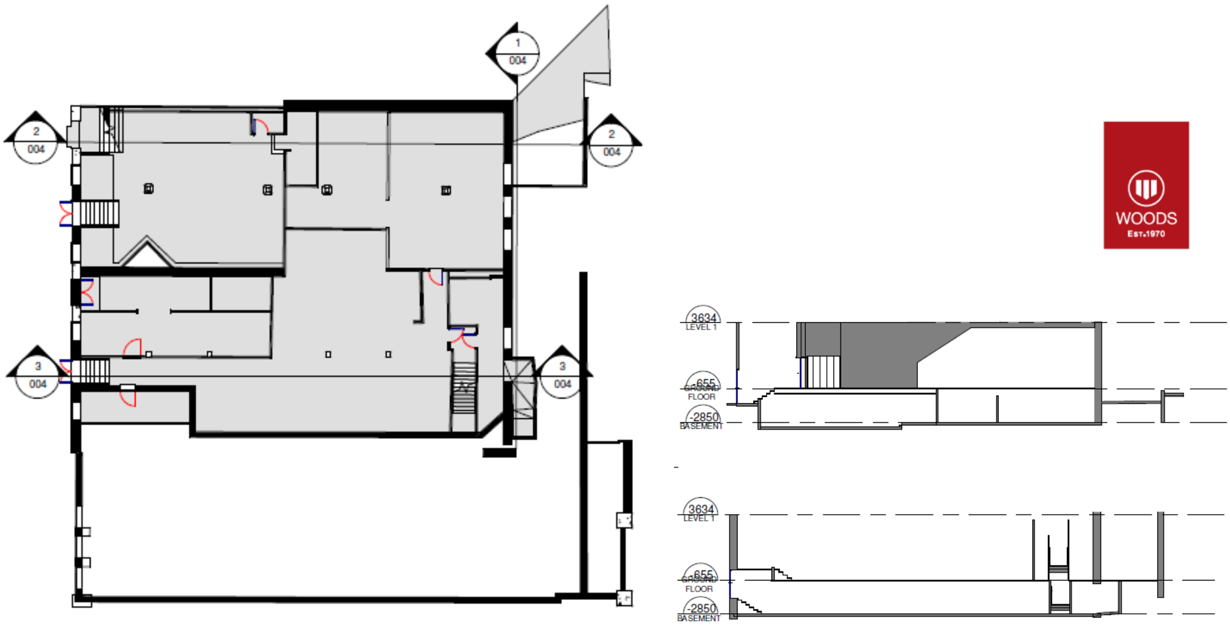
The following digital deliverables were extracted from the finalised point cloud:

- A rendered 3D Model of the building
- Floor plans of the basement and ground floors
- Sections through the basement and ground floors
- A high-quality photorealistic mesh of the outside of the building, which will serve as an accurate record of the original location and state of the building

[Figure 12] The 3D model overlaid on the point cloud it was extracted from



[Figure 15] 3D Reality Mesh of the NG Building in its original location



[Figure 13] 2D plans and profiles extracted from the point cloud

[Table 5] Effort Involved for Ng Building Case Study

Task	Time taken
Planning	0.5 day
Field data capture	1 day
Process a point cloud	0.5 day
Generate 3D Reality Mesh	1 day
Extract a 3D model	6 days
Extract plans / sections	1 day
Total	10 workdays

Outcomes

We were able to complete the capture of the building on a Saturday and deliver the results within a week.

The full, immersive 3D reality mesh and rendered 3D models will be a valuable record of how this important building once stood in its original location.

[Figure 14] A rendered 3D Model of the NG Building

THE FUTURE

While the adoption of 3D laser scanning has very much come of age with the maturing of laser scanning technology over recent years, this will only accelerate further in the future. We are already seeing laser scanning technology trickle down into consumer grade devices such as smart phones.

The availability of fully autonomous laser scanners, from flying laser scanners to laser scanners on robotic carriers will allow greater freedom to capture the physical environment and will promote benefits in productivity, safety and data completeness.

This future technology will see the routine capture of 3D digital data for large and small projects and designers will come to expect the availability of such data, especially for applications such as heritage buildings, statues and underground features (archaeological dig sites, sewers, tunnels), and also large areas including natural and manmade landscape features.

BLK Autonomy makes reality capture fully autonomous, from laser scanning and data processing to the creation of

The methods of sharing and interacting the data will evolve quickly to enable high-quality deliverables, precise insights, and immersive experiences that will see the further utilisation of mass 3D data by industry and the public. This could include using the 3D data for:

- Movement of asset management database systems into 3D space
- Virtual tours, briefings, H&S applications
- Public engagement
- Increased digitisation of museum pieces for virtual viewing
- Augmented reality representations of past streetscapes and heritage features
- VR experiences and gamification

CONCLUSIONS

Laser scanning plays a vital role in heritage conservation and around the world, laser scanning advancements are enabling the digitisation and preservation of important historical buildings and creating unique experiences that previously would have been unimaginable. 3D Laser Scanning is perfect for capturing the complex nature of historic structures, identifying any issues to be addressed with engineering and for preserving them in perpetuity.

Digitally preserving historical assets typically involves creating a digital copy of the subject through a combination of technologies which could include laser scanning, high resolution terrestrial photography, overhead aerial photography using drones and even ground penetrating radar (GPR). These techniques are all non-invasive and suitable for precise data capture without having any impact on the structure.

The user-friendly interfaces and affordable price points, mean that 3D laser scanning can be carried out by a wide range of professionals. The decision on whether to complete the survey in-house or contract a surveyor should be guided by the scale of the subject, the end purpose of the survey and the level of accuracy required. For positive outcomes, it is vital that the correct questions are asked when commissioning a point cloud survey so that the end digital deliverables are fit for purpose.

- The scope, level of detail and accuracy specified have large implications on the cost of a survey
- It is important to specify nature of deliverables so that the data is usable
- The raw 3D point cloud is the real and truest representation of a structure
- Modelling from point clouds is often not required as modern software support for the easy interaction of point clouds means that it is often sufficient for design.

As the local New Zealand case studies have demonstrated, new methods of sharing point clouds and models derived from them, allow immersive and engaging virtual site visits means that these deliverables produced with 3D laser scanning can be used beyond heritage. The information can also be used to help expand the scope of heritage projects, engage sponsors and even increase both physical and virtual tourism.

ACKNOWLEDGMENTS

Thanks to Global Survey New Zealand for allowing me the time to complete this paper as well as the use of the RTC360 laser scanner.

Thanks to Richard Harrison, my colleague at Global Survey, for assistance in scanning the Tug Lyttleton and providing invaluable review and feedback on this paper.

Thanks to Michal Tutko from Eliot Sinclair & Partners for contributing the Christchurch Arts Centre Case Study.

Thanks to Maksym Khovalko from Woods for his assistance in capturing the NG building and for the Woods team for generating the digital deliverables.

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[1] Historic England 2018 3D Laser Scanning for Heritage Advice and Guidance on the Use of Laser Scanning in Archaeology and Architecture. Swindon, Historic England. Accessed last on 27/09/2021 from **https://historicengland.org.uk/images-books/publications/3d-laser-scanning-heritage/**

[2] HNZ – Archaeological Guidelines series No. 1 Investigation and Recording of buildings and standing structures – Survey levels 1-3. November 2018. Accessed last on 27/09/2021 from **https://www.heritage.org.nz/~/-/media/2793010e741541cfbc24ba23feb22520.ashx**

APPENDICES

Appendix A – A guide to Terrestrial Laser Scanners

Tripod Based Laser Scanners

Tripod based laser scanners, often referred to as terrestrial laser scanners, capture the most accurate, dense, and uniform point clouds as well as the highest quality imagery. There are a range of terrestrial laser scanners available, which are differentiated by their speed, range and accuracy.

Terrestrial laser scanners capture a full sphere of coverage from each setup. All of the scanners above also capture a panoramic image at each setup. This can be useful for site inspection purposes (enabling a street view type tour of a site) but the main purpose is to provide the real colour values used to texture the point cloud in real world colour.

As all measurements require a direct line of sight and are limited by the range of the instrument, it is normally necessary to move the scanner around a subject of interest to capture it in its entirety. The process of linking this sequence of neighbouring setups is known as point cloud registration. Traditionally, setups were registered using common targets placed in the scene. This technique can produce very good results but is very time consuming in the field and requires some survey knowhow in order to place targets correctly to achieve the best results. More recently, the speed at which full dome scans can be captured, as well as the advancement of effective algorithms in software, has made cloud-to-cloud registration prevalent. Cloud-to-cloud registration links setups together using common features identified in overlapping cloud. The more structure in the scene, the more tightly the neighbouring scans can be joined.

Cloud-to-cloud registration performs best in indoor environments or outdoors when in close proximity to strong geometric structures. For sparse featureless environments or noisy environments, such as vegetated areas, target based registration will produce tighter registration.

Modern scanners are complimented by software running on connected tablets, which allows registration in the field. This simplifies the workflow and allows users to visualise the data captured and leave the site knowing they have the data they need to meet the scope of the project.

[Table 6] Tripod Mounted Scanners

	Entry Level	Mid Level	High Level
Example Instrument	**Leica BLK360**	**Leica RTC360**	**Leica P-Series**
			
Environment	Mainly Indoors	Indoor/Outdoor	Mainly Outdoors
Typical project sizes	Small	Medium/Large	Large
Main Characteristic	Simplicity & Portability	Performance & Productivity	Versatility & Precision
Level of Detail	Low	Medium/high	High
Max Resolution	(6mm @ 10m)	(3mm @ 10m)	(0.8mm @ 10m)
Range (typical/max)	Short (20/60m)	Medium (40/130m)	Long (70-270/1000m)
3D data quality	Good	Very good	Best
Registration	Cloud-to-cloud	Cloud-to-Cloud	Target based Surveying Procedures
Typical Applications	3D Documentation of small build environments	Accurate as-built of larger scale built environments	High accuracy analysis such as floor levelness or wall verticality

Mobile Laser Scanners

If the resolution and accuracy requirements of the project are more relaxed, mobile laser scanners present a much more quick and flexible method of capturing a site. Rather than being constrained to setup locations and requiring significant overlap to link the setups together, mobile laser scanners allow the user to simply walk (or drive) through a site and simultaneously locate and map on the fly. SLAM (Simultaneous Location And Mapping) technology tracks features in the environment that help position the scanner in 3D space The trajectory is recorded for the entire scanning session, so a unified dataset of the entire space scanned is obtained. Some mobile laser scanners, such as the Leica Pegasus backpack, fuse GNSS technology into the solution so that the point cloud is simultaneously georeferenced in real world coordinates. This dramatically reduces both the time spent on site capturing data and the post-processing required back in the office.

Mobile laser scanners have reduced accuracy (6-15 mm / 20mm absolute), less uniformity and less density in the point clouds they produce, and no HDR imaging, but the speed of capture and post-processing is significantly faster than tripod based scanners.

[Table 7] Tripod Mounted Scanners

	Handheld	Wearable	Airborne
Example Instrument	**Leica BLK2GO**	**Leica Pegasus Backpack**	**Leica BLK2FLY**
			
Environment	Mainly Indoors	Indoor/Outdoor	Areas inaccessible from the ground
Typical project sizes	Medium/Large	Large	Small/Medium
Main Characteristic	Fast and Agile	Large scale indoor/outdoor mapping	Autonomous scanning of hard-to-access areas like rooftops and facades
Level of Detail	Low	Low	Low
Max Resolution	Varies based on speed of capture	Varies based on speed of capture	Varies based on speed of capture
Range (typical/max)	Short (10/25m)	Medium (40/130m)	Long (/1000m)
3D data quality	Good	Better	Best
Registration	SLAM/VIS	SLAM/IMU/GNSS	SLAM/VIS/GNSS
Typical Applications	3D Documentation of large built environments	3D Documentation of large indoor/outdoor environments	Buildings and other large structures

Appendix B – Options for the utilisation of point clouds

Free Point Cloud Viewers

License free point cloud viewing software, both as desktop applications such as Leica TruView Digital Reality Viewer and web-browser based solutions such as Leica's TruView Live, allow anyone to easily and intuitively view and work with point cloud data without expensive computer hardware and software. Point cloud viewers typically allow 3D navigation of the point cloud and spherical imagery captured in the field as well as additional metadata such as assets or points of interest tagged in the point cloud. These tools also include the ability to measure coordinates, distances, angles, and areas directly off the point cloud.

The advantage of sharing the raw point cloud, rather than models and drawings derived from it, is twofold. Firstly, this avoids the time and expense involved in converting a point cloud into a model. Secondly, the accuracy of measurements are not diminished by best fit modelling, which inevitably comes at some cost to accuracy.

3D Reality Mesh

A mesh model consists of vertices, edges, and faces that use polygonal representation to define a 3D shape. Mesh models, which can be derived from point clouds from laser scanners, from photogrammetry or from a hybrid of the two using specialist software, provide a lightweight, photorealistic ways of delivering a digital replica of a site which is less abstract to the layperson than a point cloud. A reality mesh offers a way to efficiently model the detailed shape of the structure, for example it may represent the true contour of a rough stone façade.

3D Building Information Models (BIM)

Point clouds are commonly converted into solid 3D elements or surface models known as BIM. Scan to BIM workflows offer two distinct advantages. Firstly, modelling simplifies the data, shrinking the data file size. BIM models are much smaller in size than a point cloud, enabling the easier sharing and utilisation of the 3D data in CAD software. Secondly, the BIM model is the structure to which historical documentation, and other parametric data associated with the site can be attached, providing a shared knowledge resource for information about a facility and forming a reliable basis for decisions during its life-cycle.

A 3D BIM model includes modelled elements which are an approximation of the shape of the structure, specified as a Level of Development (LOD). The required LOD varies according to the project requirements, commonly between LOD200 and LOD450. A higher LOD requires additional time and cost to model and consequently, LOD needs to be carefully and appropriately specified.

2D Drawings

2D drawings can be extracted from point clouds to produce plans, profiles and cross-sections.

Topographical plans can be extracted by 'virtual surveying' workflows where topographical features are extracted into points and linework by tracing off the point cloud. Profiles can be drawn by tracing of orthographic image of the point cloud, while cross-sections can be extracted by tracing slices of the point cloud, normally through the X, Y or Z axis.

2D drawings are a considerably compromised extraction from the full 3D dataset, yielding only a fraction of the available data and requiring expertise to interpret. We can expect to see the utilisation of 2D data continue to decline as more consumers of the data become adept at handling the rich 3D data.

EARLY ENGINEERING INVENTION

engineering new zealand HERITAGE

EARLY ENGINEERING INVENTION: WRITER BIOS

IAN BYWATER, BSC(ENG), FENGNZ

A graduate of Queen Mary College, London, Ian began work with the Eastern Electricity Board before joining New Zealand Electricity in Invercargill (Southland Electricity Power Supply). He then held positions in Christchurch (Heathcote County Council electrical engineer, Port Hills Energy manager, SouthPower business development manager) before working for environmental companies (Convertech and Natural Systems). Ian represents the hydro-turbine company Turab.

IAN MACGREGOR BE (CIVIL), MHKIE, MIET, CENG, CMENGNZ. RETD.

Civil, Production, Geotech Investigations Engineer. Materials Engineer Ministry of Works and Development. HKIE Materials Division Assessor & Assoc Prof City University of Hong Kong. Published research papers include: precast white concrete formwork, properties of stone flooring, pressuremeter & dilatometer test analysis. He is a member of Heritage New Zealand, and the Tramway Historical Society. Lived 80m from the Maryhill cable car line.

MILES PIERCE BE (ELEC), FIE AUST CPENG RETD.

Miles spent most of his career with GHD Consulting Engineers where he was for many years Principal Electrical Engineer in their Victorian practice. He has had a long-term interest in engineering and industrial history and heritage, particularly in relation to electrical and mechanical engineering disciplines, and has authored a range of papers in the field. He is a committee member and a past chairman of Engineering Heritage Victoria.

'BOTTLED LIGHTNING' – NEW ZEALAND'S FIRST PUBLIC ELECTRICITY SUPPLY

Ian Bywater B.Sc.(Eng) F.Eng.NZ

Summary: Dunedin electrical engineer, Mr Walter Prince, promoted a hydro-power scheme for Reefton at public meetings in 1885. He suggested an upstream off-take of the Inangahua River be fed through a rock tunnel and a timber-lined water flume to a power house close to the town.

Two subsequent replacement power stations were built on the same site before generation ceased altogether. After decades without a power station local enthusiasts formed the Reefton Power House Charitable Trust to raise funds to reinstate hydropower for the town. Commissioning a 250kVA turbine is anticipated in early 2022.

THE BEGINNINGS

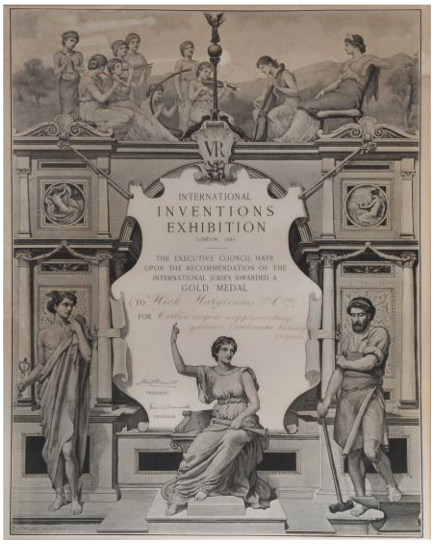
The Electric Age has grown from the experiments into electro-magnetism by Michael Faraday (1791-1867). He has been named the "father of electricity" for his invention of the electric motor and the electric generator. These discoveries then led to subsequent inventions using electricity for lighting by incandescent lamps (independently by Thomas Edison, USA and by Joseph Swan, UK), and by arc lamps, a phenomenon demonstrated by Humphry Davy (1778-1829) as early as 1802.

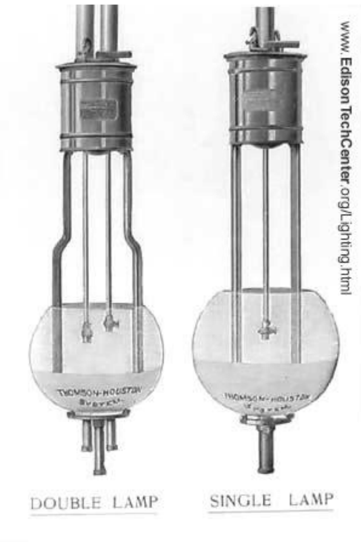
The "Great Exhibition of the Works of Industry of All Nations" was an international exhibition which took place in Hyde Park, London, in 1851. Then in 1885 an Inventions Exhibition was held in both London and Antwerp, at which the Immisch Company gained the "Highest award for Electric Motors" and Gold Medals were awarded to both Thomson-Houston and Edison-Swan for Lighting Systems [1]. A New Zealand Industrial Exhibition was held in Wellington the same year. Walter Prince was one of the exhibitors showing "electric apparatus". At the time Prince was working for Messrs R.E. Fletcher & Co of Dunedin, a firm of electrical engineers and contractors. He had previously been employed with the Union Steam Ship Company, with its Head office on Water Street, Dunedin.

Prince was the travelling salesperson for Fletchers, visiting city councils and harbour boards up and down the country extolling the virtues of electricity over gas lighting. One early project that Prince was involved with was at the Phoenix Mine at Bullendale, Central Otago, which he visited in November 1884. The proposal was to divert water from the left-hand branch of Skipper's Creek to a Pelton Wheel turbine to drive a DC dynamo. The output would be for lighting, and converting the powering of its quartz stamper-baiery to an electric motor rather than its water driven belt-drive [2]. This entailed installing "two 20kW Brush generators and a 50 horse-power Brush Victoria motor," as well as for lighting in the baiery shed. At the same period, Prince was also involved with staging a demonstration of electric lighting for the Auckland Harbour Board wharf.

Matters turned sour when Prince was thrown from his horse in Queenstown, while supervising the work at Bullendale, sustaining a serious head injury and was taken to a Dunedin infirmary to be nursed. Fletchers, without Prince, were unable to solve problems which then arose at Bullendale. Also, without completing the demonstration of electric lighting in Auckland, the Harbour Board decided to install gas lighting for its wharf instead. Prince did make a full recovery, but no doubt because of these two events Fletchers 'dispensed with his services'. Prince, armed with knowledge gained while working for Fletchers, then set himself up in the electricity business.

Prince's company from then on advertised electrical goods from the newly established manufacturers of electric lighting using carbon arc lights (Thomson-Houston, USA) [3] and by incandescent lamps (Edison-Swan, London) [4] and the means to generate the required electrical current from "electro-motors" (Immisch, London) [5]. Walter was certainly "up with the play" with the new electrical goods being produced in America and Europe.

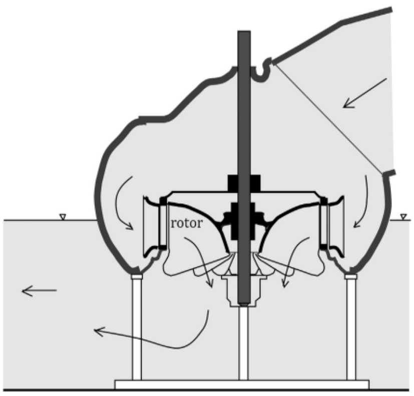


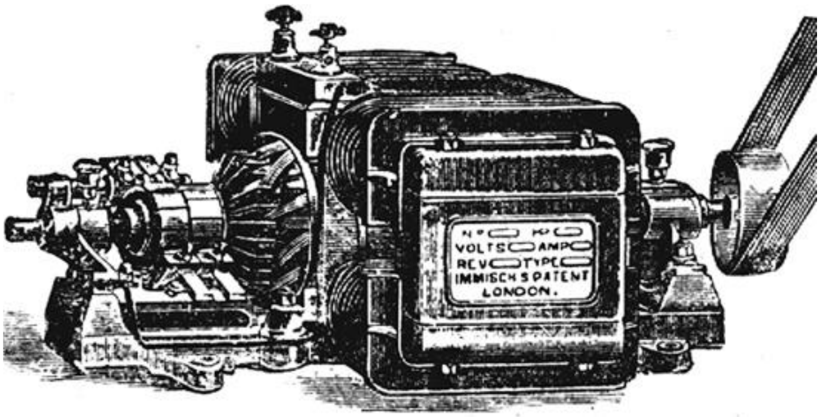


Left: [Figure 1] International Inventions Exhibition certificate. International's Inventions Exhibition certificate, Wikipedia [***https://en.wikipedia.org/wiki/International_Inventions_Exhibition***](https://en.wikipedia.org/wiki/International_Inventions_Exhibition)

Middle: [Figure 2] Early arc lamps. Edison Arc lamp, illustration from Edison Tech Centre, [***https://edisontechcenter.org/ArcLamps.html***](https://edisontechcenter.org/ArcLamps.html)

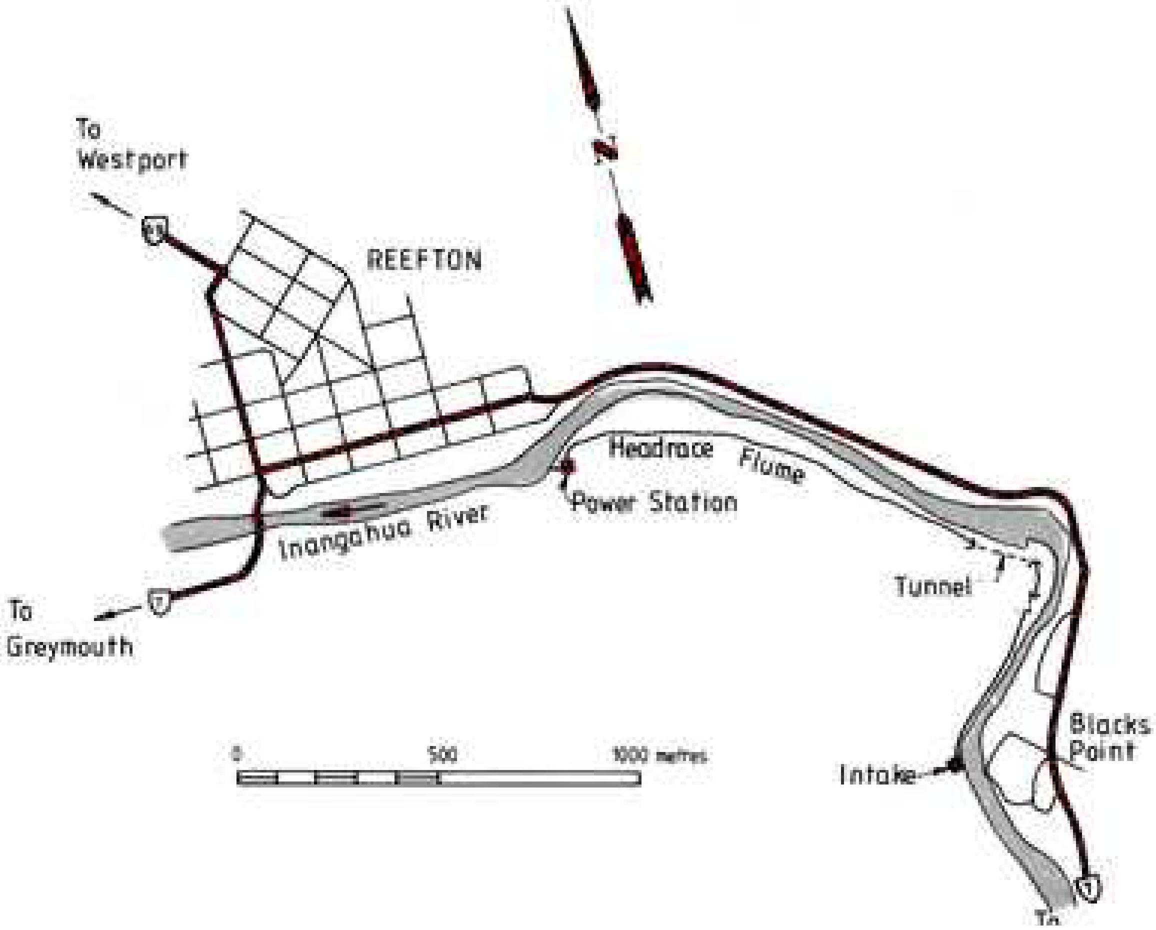
Right: [Figure 3] Early incandescent lamp. Swan incandescent lamp, illustration from [***https://www.bulbs.com/learning/history.aspx***](https://www.bulbs.com/learning/history.aspx)





Left: [Figure 4] Cross-section of a Francis turbine c.1888. Francis turbine cross-section, illustration from ResearchGate web page [***https://www.researchgate.net/figure/Simplified-view-of-a-180-kW-Francis-turbine-manufactured-in-1882-by-the-Humphrey-Machine_fig7_318502311***](https://www.researchgate.net/figure/Simplified-view-of-a-180-kW-Francis-turbine-manufactured-in-1882-by-the-Humphrey-Machine_fig7_318502311)*.*

Right: [Figure 5] Immisch Dynamo. Immisch dynamo, Electric Boat Association webpage [***https://www.electricboatassociation.org/history/***](https://www.electricboatassociation.org/history/)



[Figure 6] Reefton power station hydro-scheme, New Zealand Engineering 1988, Electricity Supply in New Zealand, amended by author. Note: The scheme has only one tunnel through rock. Originally part of the wood flume south of the tunnel was covered to protect the headrace from falling debris, and called the "earth tunnel".

By the 1880s, Reefton was a well-established frontier town on the West Coast on the banks of the Inangahua River. It owed its beginning to the gold bearing quartz reefs discovered by Richard Shiel in June 1870. Gold towns rapidly expanded to support the daily needs of the community; the "butchers, bakers and candlestick makers". In fact, along the shops of Broad Street, Reefton, among the usual businesses for daily life there were four Sharebroker and Commission Agents and no less than 17 Hotels. Reefton had grown rapidly since its beginning and had wealth.

A committee of Reefton businessmen had invited Prince to the town in 1883 while he was organising a demonstration of lighting for the Lyttelton Harbour Board. He investigated the local terrain and produced sketched plans for a hydro-electric scheme taking water from the Inangahua River. Through lack of finance and any strong appetite to proceed the scheme lay dormant. Then in 1886 Prince, now self-employed, returned to Reefton at the request of a local committee of businessmen to demonstrate his electric lighting techniques. This came after one of the committee, G.R Wylde, had recently returned from Melbourne with an Edison-Swan bulb, where he had seen them in operation.

Prince arrived in town bringing a 1kW dynamo and lamps to demonstrate his wares. He was able to drive the dynamo by using the local Oxley Brewery's steam engine. He wired up lights in four of the main hotels: Kater's, Williams's, Stevenson's and Dawson's. The demonstration went live on the evening of 24 November 1886. To the general inhabitants it must have been an astounding experience as Reefton had no public gas supply and lighting came either from burning candles or oil lamps. To the businessmen, it was an extremely attractive investment, bolstered further by articles in the two local newspapers: the Inangahua Herald and the Reefton Times. The Herald with an article boasting of Mr Prince's past achievements at the Phoenix Mine, while the Times had a story from France of electricity being transmitted 35 miles with "little loss of voltage" [6].

Prince stayed on giving three evening lectures in the Oddfellows Hall about the powers of electricity, charging three shillings for a front row seat, and two shillings elsewhere. He was a gifted salesman; he employed the phrase "Bottled Lightning" to described electric lighting, which described the phenomenon well. He stressed the safety of using electric light; it didn't need a match to light to cause fire and it did not remove oxygen from air. He also demonstrated for the benefit of the gold miners in the audience, how an electric motor could power a 10-stamper quartz crushing plant.

Prince was indeed a qualified futurist; he is quoted as saying, "we may look on the winds, the tides, the running rivers, the torrents, the cataracts and perhaps even the surging billows of the sea as newly apprenticed servants of our necessities and luxuries".

Two weeks after the demonstration a committee of businessmen met in Dawson's Hotel and resolved "that a company, the Reefton Electrical Transmission of Power and Lighting Company, be formed" to provide a public electricity supply. The company was floated with 20,000 shares on offer at 5 shillings each [7].

THE HYDRO-ELECTRIC POWER SCHEME

Prince had already sketched his ideas for the power station on his first visit in 1883. The gentle gradient of the Inangahua River upstream of Reefton meant that the best prospect was to divert water above the bend in the river at Blacks Point, north of the town. An open wood-flume would take diverted water to a tunnel in the rock bluff on the left hand riverbank, and continue to the station site on the opposite side to the town. The overall distance would be 1.8km and provide a useful head of about 8 metres. It is no wonder, therefore, that it took almost two years to complete the civil works, install the generating plant and reticulate the power to the town.

The station had a 70 horse-power (hp) turbine and a belt-driven 20 kilowatts (kW) 30/110 volt Crompton bipolar dynamo. This was enough to supply sufficient power for 500 lamps in the town [8]. The turbine was most likely built by Scott Brothers, Christchurch. The dynamo was imported from Britain by Forsyth & Masters, Reefton's hardware store on six-month terms.

On 1 August 1888, the town gathered to witness the first operation of the power plant to light the main street, Broadway. The Inangahua Herald described it thus: "The bright luminous rays of the arc light burst forth, lighting up the whole scene with a strange but dazzling brilliancy." By September 19, it was congratulating itself on being lit by the new modern lighting method.

Like all first examples of a new technology, the scheme did not come without its problems. First, its cost had exceeded budget by 20%, reaching £6,000. Then, as was to be expected, faults with supply began to emerge, particularly with the underground section comprised of bare wires set in bitumen. And, with these problems Prince as the company's chief engineer, came under pressure to produce solutions. With no satisfactory solutions readily on offer, Prince for a second time, had an employer 'dispense with his services'.

THE LATER YEARS

As the load grew various changes were made. Wood fluming was replaced with one-sided concrete walls adjacent to the steep hillside and the first generator was replaced by a 220 volt, 46kW Fynn generator, which was supplemented by a coal-powered steam engine.

In 1908, a second powerhouse replaced the original building. A new 110hp Boving horizontal Francis turbine was used and the power output increased to 80kW. Further steam driven generators were added in 1920 and included a 230 volt DC Lawrence Scott 100kW generator.

Then in 1935 a larger Boving Francis turbine and Thomson-Houston 3-phase AC generator were fitted in a third building adjacent to the second building. Finally, the station was purchased by the Grey Electric Power Board in 1946. It ceased operation three years later when Reefton became part of the national grid. The second and third powerhouses were demolished in 1961, and these foundations are a Heritage New Zealand historic category 2 site [9].

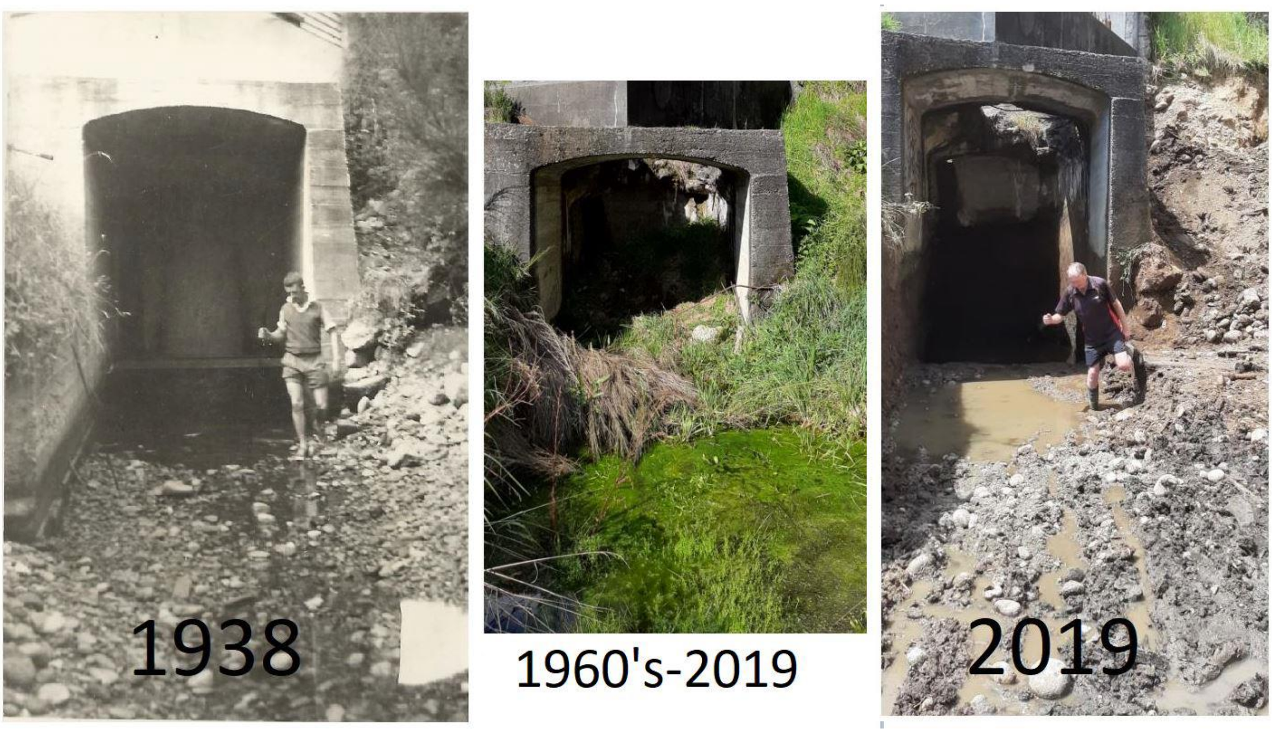
A NEW POWER STATION

Some seventy years later Reefton is about to see the return of its power station, on the same site using the same water course with a modern, high efficiency turbine/ generator. It will be sited close to where the first powerhouse stood, and in a building closely matching the style of the original.

The Reefton Powerhouse Charitable Trust Incorporated was formed in 2010 by a band of local enthusiasts with a passion to bring a tourist attraction back to the town. Its aim is to restore generation with a new power station and new plant using the original water course. Later, as funding allows, the plan is to build a replica of the second and third station buildings on the old foundations to operate as a visitor information centre and museum of artefacts of the original and subsequent stations' history. Access to view the new station and information about its design also will be provided. The revenue generated by the modern station supplying Westpower's network would also support this latter project. A fitting name for this would be the Walter Prince Visitor Centre particularly for his vision of the future might be in harnessing "the winds, the Ades, the running rivers,…and even the surging billows of the sea."

The new turbine is a 4-bladed, axial flow, variable pitch turbine inclined at 45 degrees directly coupled to a 250kVA, 400 V, 50 Hz, 600rpm synchronous generator. Turab of Sweden manufactured the turbine, supplied the draft tube, and the G&Em generator manufactured in the Czech Republic. The package arrived in Lyttelton in September 2020.

[Figure 7] Intake. Photo supplied by Reefton Powerhouse Charitable Trust Inc.



[Figure 8] Tunnel exit. Photo supplied by Reefton Powerhouse Charitable Trust Inc.

Left: [Figure 9] Headrace. Photo by author.

Right: [Figure 10] Old station headworks and foundations. Photo by author.

To date (late 2020) re-instating the headrace from the original river off-take structure, passing through the tunnel and round the foot of the bluff has been completed. This involved extensive rock bunding south of the tunnel replacing the later one-sided concrete wall, which had superseded the original wooden flume.

North of the tunnel the later original concrete formwork has been preserved and extensively repaired. The tunnel was cleared of accumulated debris and the floor and walls shotcreted.

The work to construct an open top wood flume crossing open ground to the penstock is planned for the fourth quarter of 2021. At the junction of the rock bunding to the wood flume, there will be the facility to shut off the flow to the station and allow the flow to follow a natural depression back to the river. The new powerhouse construction is scheduled to commence the first quarter of 2022, and installation of the tubine generator thereafter.

THE FIRST PUBLIC ELECTRICITY SUPPLY

Reefton is seen as the first public electricity system in New Zealand, if not the southern hemisphere. Certainly it is the first recorded in New Zealand, but do other candidates exist to this claim elsewhere?

Looking to the northern hemisphere, Thomas Edison helped form the Edison Electric Illuminating Company of New York, which brought electric lighting to parts of Manhattan in 1882, (and by 1887 there were 121 Edison power stations across America).

In Europe, La Roche- Sur-Foron, France, claims to be the first city in Europe to have public electric lighting in 1882. Twenty public candelabras and six hundred Edison bulbs lit up the houses of that small merchant city close to the Swiss border. Le Figaro wrote: “It is neither Paris, nor London, nor Berlin, or Moscow, or anything like that. It is a very small city (…) ten leagues from Mont-Blanc; it is not even a canton capital answering to the name of La Roche. Well, this city, which I would like to call the City of Light, (…) the first in Europe, to have electric lighting in its streets, squares, monuments and houses.”

Other early public generation sites in Europe are Blackpool (UK), Godalming (UK), Timisoara (ROM), Harnosand (SWE), Bellegarde-sur-Valserine (FRA), Darmstadt (DE), Tivoli (ITA), Piossasco (ITA). These towns are members of an association “Starter”, formed to communicate the earliest locations of public electricity supply. By 1890 the world's first coal-fired public power station, the Edison Electric Light Station, was operating in London.

The role of electricity to supply lighting, heating and power was expanding rapidly and continued this rapid advancement around the world until more than a century later it is an unequivocal essential to everyday living. Walter Prince, and others, who extolled the benefits of electricity back then were at the birth of the Electric Age.

REFERENCES

[1] Thomas Edison and Joseph Swan settled their dispute as to who patented the incandescent lamp by forming the Edison & Swan United Electric Light Company Ltd, in 1883.

[2] As an example of a quartz stamper-baiery view NZ Heritage's site of the Homeward Bound stamper baiery near Macetown, Central Otago hips://www.youtube.com/watch?v=BBZv9J8FzAI&t=1s

[3] Founded in 1882, from a merger of the two companies of Elihu Thomson (1853 – 1937) and Edwin Houston (1847 – 1914), Massachusetts, USA.

[4] Founded in 1883 by Joseph Swan (1828-1914), London, by agreement with Thomas Edison (18471931), New York.

[5] Moritz Immisch (1838 – 1903), London, UK. A naturalised British citizen from Germany, manufacturer and prolific innovator of electric vehicles, boats and trams.

[6] Electrical power was still a contest between those advocating direct current (DC) and those advocating alternating current (AC) systems.

[7] The company's capital of £5,000 in1888 Q4 is equivalent to $1,065,487.55 in 2020 Q2.

[8] https://www.engineeringnz.org/programmes/heritage/heritage-records/reefon-power-station/

[9] https://www.heritage.org.nz/the-list/details/5002

[10] North Island 500,000 h.p. (380 MW) installed capacity y/e 2008, 1,865 MW South Island 3,200,000 h.p. (2,400 MW) installed capacity y/e 2008, 3,600 MW

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APPENDIX: HISTORY OF ELECTRICITY SUPPLY IN NEW ZEALAND

In his presidential address at the 1943 AGM of the Electric Power Board and Supply Authorities Association of New Zealand, Mr. J. A. Smith, AMIEE, AMNZIE, of Levin, dealt with the history of electricity generation and supply in the Dominion. He stated. that the Dominion's electrical history now extends over a period of sixty years, and much of the pioneering work is worthy of note. But early records are so meagre and so scattered that interesting information is in danger of being lost for ever.

EARLY LEGISLATION

In 1954 the "Electric Line Act" made provision and conditions relating to the erection of electric lines for both telegraph and lighting purposes. This Act was derived from the "Electric Telegraph Act" and its amendments, formulated during the period 1865-1875 and probably the earliest reference to electricity in New Zealand, but hardly concerned with electricity generation and supply as we know it to-day. An "Electric Motive Power Act" 1896 gave authority to the Government to make investigation into the possibility of utilising the waterways of the Dominion for the purpose of supplying electricity to the gold mining industry which was an important one in those days. Special Acts of local importance only, were passed between 1890 and 190 giving powers to various local authorities and companies to erect and operate electric power plants.

The basis of the present extensive development was probably established when the Government passed the "Waterpower Act" 1903 which reserved to His Majesty, subject to right lawfully held, the sole authority to use water in lakes, falls, rivers or streams for the purpose of generating or storing electricity or other power. As a result of this Act, an investigation of the Dominion's available water-power was made by Mr. P. S. Hay, Superintending Engineer of the Public Works Department, whose classic report printed in 1905 showed that some 500,000 h.p. was available in the North Island with some 3,200,000 h.p. in the South Island [10].

FIRST GENERATION

The history of electricity generation in New Zealand commenced well back in the eighteen-eighties when some mining companies in Otago installed water-power plants. There were quite a number of early D.C. installations for gold mining purposes, away in almost inaccessible parts of Otago and Southland. One installation, a hydroelectric quartz-mining and crushing plant working on 1200 volts dated back to 1885. This was near Skippers and comprised a 100 h.p. Pelton wheel driving two “Brush" dynamos and transmitting electricity about two miles for lighting and power. Records are incomplete, however, and the "Sandhills Dredge" designed and put into operation in 1889-90 by the late. Mr. R. C. Jones, afterwards one of the founders of Messrs. Turnbull and Jones. Ltd., worked on the Upper Shotover River in Central Otago at 1300 volts D.C. and is usually claimed to be the world's first electrically operated gold-dredge.

It was a complete success and was followed in about I899 by the "Fourteen Mile Beach Dredge." This was a 2,300 volt, 3-phase, 50 cycle installation—total power being about 150 h.p.— that is about one-tenth of the size of to-day’s big dredges. Another early scheme was that of the Phoenix Goldmining Company who in 1895 installed a plant at Miller's Falls, Otago, and in 1900 had a plant operating which supplied power for a bucket dredge.

THE BEGINNINGS OF PUBLIC SUPPLY

Although there was a proposal in 1882 to spend £200,000 for electric lighting in Wellington, the honour for having the first plant for supplying electricity to the public belongs to Reefton. Early in 1886 Dawson's Hotel sheltered a company of financiers who had come down to investigate the gold mining with a view to investing capital. The financiers were not the only hunters in the field, however, for another enthusiastic gentleman had already been in Reefton for some days, and he had brought with him for demonstration purposes, a machine that was the wonder and talk of the whole district. This man was one Walter Prince who quite evidently combined a knowledge of the then mysterious "electric current" with considerable ability as a salesman and company promoter.

Where Mr. Prince had come from originally cannot now be found out, but the 1 kilowatt dynamo he brought with him is said to have been a machine of his own manufacture. There seems no doubt that he came to Reefton with the object of promoting a company for the purpose of giving a public supply of electricity, and although he seems to have failed later on the technical side, he certainly attained success in his primary object, for the company was duly formed. His first move was to give a demonstration of the “light" and to this end he made arrangements with "Edwards" Brewery to have his dynamo belt-driven from their steam-engine, carrying his conductors underground between two laths of Amber to Dawson's Hotel, which was thus lit electrically in 1886 for the edification and enlightenment of Reefton in general and the financiers in particular.

On February 2nd, 1887 arrangements were made with Mr. Prince to "put in a plant to run 500 lights at a cost of £1800, to be paid in three instalments of £600 each," and in May, 1887 the company was registered as "The Reefton Electrical Transmission of Power and Lighting Company Ltd.” with a capital of £5000 in 20,000 shares of 5s each.

It is interesting to note that the Reefton Electric Light and Power Company, Cromptons and Scotts, are all today actively engaged in the electrical industry. Reefton's system with its reticulation of four miles of lead covered underground cable was supplying power in 18S7—that is 56 years ago and within 5 years of the commencement of the first public supply systems in America and England.

At the end of 1887 also, the Wellington City Council called tenders for the lighting of the streets by electricity. Advertisements were placed in Wellington, San Francisco and London newspapers and early in 1888 the tender of an English syndicate known as the Gulcher Electric Light and Power Co. was accepted. Under the terms of the agreement with the company, the council undertook to supply free of charge, water from their mains for operating four "Vortex" 30 h.p. turbines to be installed in two stations and to supply 500 twenty-two candlepower streetlamps.

Owing to financial difficulties, the company underwent reconstruction within a year of commencing operations, so that until 1891 activities were confined to the lighting of streets and municipal offices only. Negotiations, however, were eventually successful in obtaining statutory power for the introduction of electricity for private supply, and a new company—the New Zealand Electrical Syndicate—was formed to operate the concession. In 1892 a steam generating station was erected in Harris Street, then newly re-claimed land. The plant generated single phase current at 2,000 volts, 50 cycles, and distributed to pole transformers "stepping down" to a two wire 105 volts supply to consumers. Wellington thus became the first city in the Southern Hemisphere to adopt electricity for public street lighting.

About 1902 the City Council decided to install electric tramways, and contracts were accepted for a power station in Jervois quay. This station was placed in commission in 1904 by the city of Wellington Electric Light and Power Co., (who had acquired the rights of the N.Z. Electrical Syndicate) and comprised a battery of Lancashire Boilers with one 150 kW,, and. three 350 kW., compound wound dynamos direct connected to Bellis and Morcom triple expansion engines. In 1945 direct current was supplied for private consumers, and a substantial load—mainly lifts—was soon built up. Two motor alternators, driven from the traction supply were installed in Jervois Quay for supplying street lighting circuits.

In August, 1907, the whole of the generating plant throughout the city, together with reticulation was purchased from the company by the Wellington City Corporation for £160,000. At the time of the transfer, there were about 5,500 consumers and an annual consumption of just over 2,000,000 units. To-day's figures are about 42,000 and 150,000,000 respectively.

FIRST MAJOR DEVELOPMENT

The first major hydro electric development in New Zealand was Waipori when a private company was formed in 1902 to develop the Waipori scheme and to supply power to Dunedin and districts. After 1907 a number of installations came into operation. The chief were Auckland (1908, using a waste heat plant similar to that in Christchurch) and Wanganui (also 1908). Taihape and Gisborne (1912); Thames and Horahora (1913). The Horahora station was built by at the Waihi Gold Mining Co., 1913, to supply power to their mine and battery at Waihi 50 miles away. The station was purchased by the Government in 1919 and in 1926 two additional units of 1900 kW were added, making the total capacity 10,300 kW. The next installations were Mangaweka, Napier and Invercargill, 1913; and Ohakune, 1914.

FIRST GOVERNMENT HYDRO SCHEME

After persistent demands to the Government during 1905-10 an "Aid to Water-power Act" was passed in 1919, and the late Mr Evan Parry was appointed Chief Electrical Engineer in 1911. In 1915 Lake Coleridge, the first Government hydroelectric scheme (that is designed, erected and run by the Public Works Department) was put into operation with an initial capacity of 4500 kW. Subsequent increases in 1926, 1927 and 1935 developed this station to its maximum output of 34,500 kW. Next tame Taumarunui, Havelock North, Waihi, Oamaru and Tauranga in 1915; Wairoa, 1916; Raetilhi 1917; Akaroa, 1918; Opunake, 1920; Fairlie, Murchison and Whakatane, 1922; Wairarapa, 1923; Mangahao (a Government scheme of 19,200 kW) installed at the end of 1924; Monowai, 1925; and Waihopai, 1927. This station at Benopai on the Waihopai River, near Blenheim, was installed at a cost of £275,000, including transmission lines and reticulation and contained two turbines each of 500 kW).

In 1929 the first two major North Island hydro-electric schemes to be undertaken by the New Zealand Government — Lake Waikaremoana and Arapuni—came into operation. The Arapuni development was commenced prior to that at Waikaremoana but Arapuni did not come into operation until May, 1939. Meanwhile with the rapidly increasing demand for electricity in the North Island and the extension of the Lake Coleridge plant to its full capacity, it became necessary for the Government to develop a further supply of power. After extensive surveys, it was finally decided to develop a site on the Waitaki River above Kurow as affording the maximum security for the transmission system, the best supply to the southern district and the most favourable conditions for future extensions. In 1928 work commenced and Waitaki was opened in October, 1934 with two units each of 15,000 kW.

Otaki Mail, 17 September 1943, p 4.

DUNEDIN'S CABLE CAR SYSTEMS – A BOLD VENTURE IN THE ANTIPODES

Ian MacGregor and Miles Pierce

Summary: In 1881 a cable car service opened from central Dunedin to the elevated suburb of Roslyn with about 1.1 km of single track that incorporated two passing loops. As such, Dunedin became the third city in the world after San Francisco and Chicago to inaugurate this form of street based public transport. Two years later, another cable car system extending 1.6 km to serve the also topographically elevated suburb of Mornington was opened. In succeeding years extensions were added to both lines and in 1900 a third tramway company opened a 2 km double track cable car service from the city to the suburb of Kaikorai.

The introduction of cable cars to the hilly city of Dunedin at the instigation of locally born engineer George Duncan was indeed a bold venture in the early days of this technology. Whilst Duncan would have had access to technical information on the nascent cable car services in the USA, he had not personally seen them in operation. Faced with a curve on a steep gradient in the lower section of the Roslyn line, Duncan devised the 'pull curve' whereby the grip cars retained their hold on the rope whilst negotiating the curves. This was a world first development that was later used on USA cable tramways.

The paper reviews the evolution of cable tramways and the engineering challenges and solutions adopted for the early Dunedin cable car systems. The paper then focuses on the construction, operation and maintenance of the Mornington cable car service.

Cable trams, cable tramways, cable cars, George Smith Duncan

PART 1: BACKGROUND AND THE ROSLYN LINE

Miles Pierce

THE EVOLUTION OF CABLE TRAMWAYS

The use of a continuous loop of wire-rope driven by an engine and to which buckets or track mounted vehicles could be coupled and uncoupled in order to propel them had its origins in mining by way of aerial cableways and the underground haulage of skips running on rails within mine tunnels. Its first successful application to propel streetcars or 'trams' was in San Francisco where Andrew Smith Hallidie, who had interests in wire rope manufacture, set up a cable tram service on the steeply inclined Clay Street. It had its first run in August 1873 and was an immediate success [Bucknall Smith 1977; Hilton 1982].

The essential elements of Hallidie's tramway comprised a cable tunnel between the tram rails in which the continuous loop of wire-rope cable ran on supporting sheaves. The cable was driven from an engine house by steam power. A longitudinal slot at grade in the top of the cable tunnel allowed the narrow shank of a cable gripping device – 'the grip' – mounted in the haulage vehicle, termed 'the dummy', to clamp onto the cable from above and thus propel the dummy along its running rails. The grip could be activated and released via a hand-wheel forming a part of the assembly and was positioned in the middle of the dummy where it was operated by 'the gripman' [Bucknall Smith 1977; Hilton 1982]. The dummy hauled an enclosed car behind it known as the 'trailer'. The cable tram, comprising dummy and trailer, was well suited to providing a convenient form of street based public transport in the hilly topography of downtown San Francisco.

Four years later another company inaugurated a separate cable tram service in nearby Sutter Street that incorporated several improvements including to the design of the cable gripping mechanism whereby a lever with a quadrant and pawl was used instead of Hallidie's handwheel and screw operated grip. Yet other lines followed, and by 1890 San Francisco had twenty-three cable tram routes totalling some 53 miles (85 km) of track. They were operated by a variety of private companies, some of which later amalgamated [Hilton 1982].

Chicago was the next USA city after San Francisco to implement the technology with its first cable tram route starting operation in January 1882. Other lines then followed such that this city hosted about 41 miles (66 km) of double-track cable tram routes at its peak. In contrast to San Francisco, Chicago's streets were essentially flat and the advantage of being able to accommodate steep gradients was not applicable. Nevertheless, the enterprise was successful until superseded by electric trams in the first decade of the twentieth century [Hilton 1982].

Cable tram systems were established in a total of twenty-nine USA cities during the 1880s [Hilton 1982]. Cable tramlines were also built in London, Birmingham, and Edinburgh between 1884 and 1889 [Bucknall Smith 1977].

THE EARLY DUNEDIN VENTURES

The first cable tramway to be constructed outside of the USA was the approximately 1.1 km long line between the CBD and the suburb of Roslyn in the hilly city of Dunedin, New Zealand. It commenced operation on 24 February 1881, comprising a single track with passing loops and included two curves [Bucknall Smith 1977; Hilton 1982]. A double track line about 1.6 km in length to service the Dunedin suburb of Mornington was commissioned two years later following the early success of the Roslyn cable tramway.

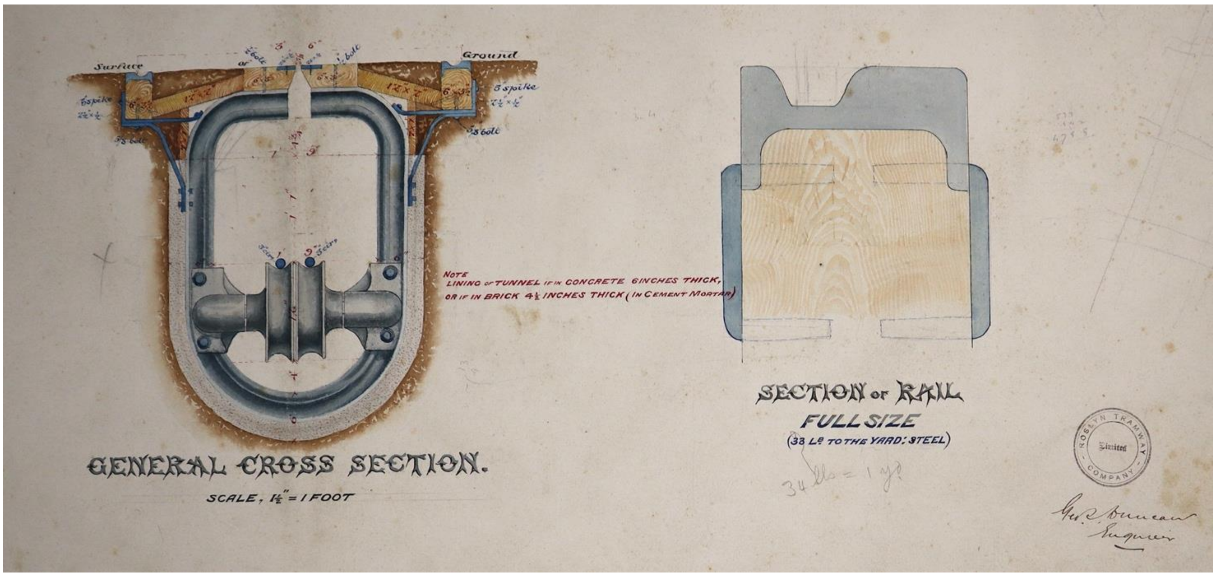
The Dunedin cable tramways were conceived by a young locally born engineer, George Smith Duncan, who in 1879 presented a proposal to the Roslyn Council on behalf of his consulting engineering firm of Reid & Duncans to construct the Roslyn cable tramway. Whilst the Council sanctioned it, difficulty was experienced in obtaining sufficient capital to float a company to build and operate the tramway. This was ultimately achieved after some modification of the initial plans to reduce the first cost. At that time, a total of five cable tramways were operating on hilly streets in San Francisco and design and construction of Chicago's first cable tramway was in hand. Duncan had not previously seen the San Francisco cable trams, but evidently obtained technical information about them when designing the Dunedin cable tramways.

When the Roslyn cable tramway opened in February 1881, and the Mornington line in March 1883, they were the first cable tramways to operate outside of the USA.

Duncan's cable tramway expertise was subsequently applied to the design and construction of Melbourne's 70 km of double track cable tramway network – the second largest in the world - when in late 1883 he accepted an offer from Francis Clapp, MD of the Melbourne Tramway & Omnibus Company, to become engineer to that company [Pierce 2019].

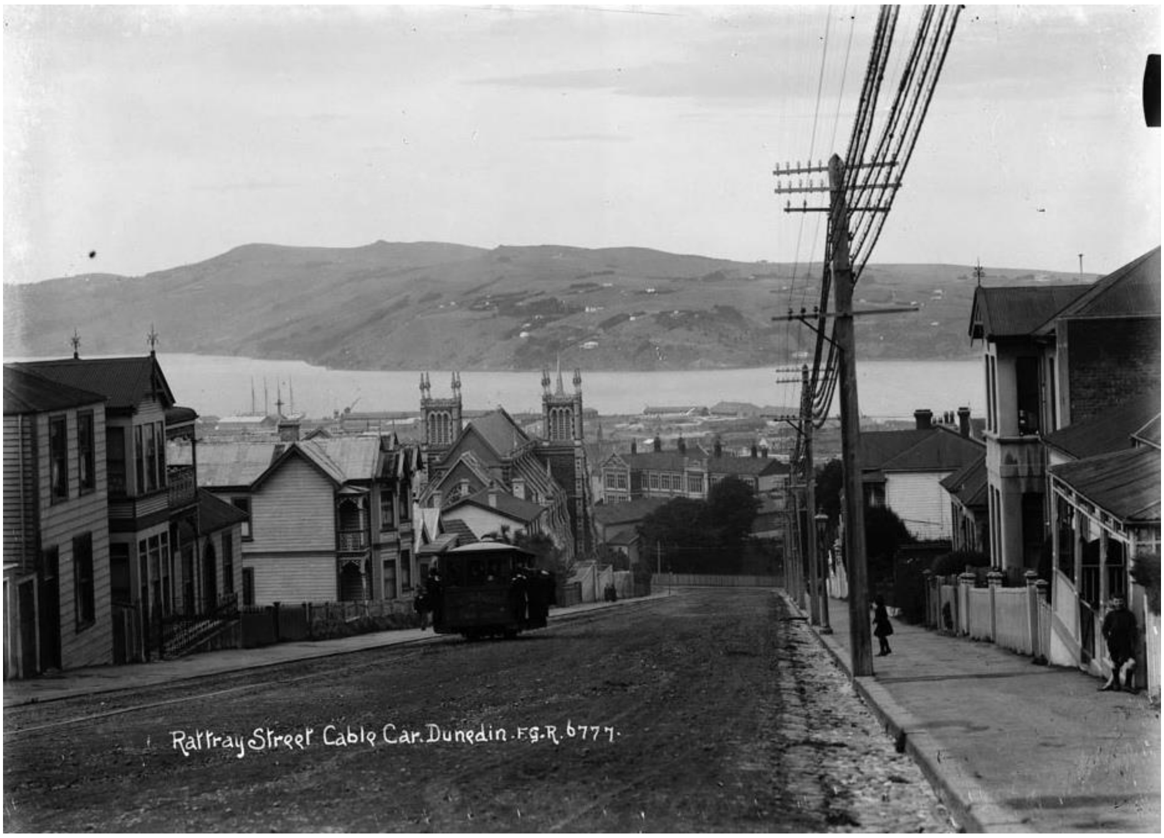
THE ROSLYN CABLE TRAMWAY

The original Roslyn cable tramway ran from the intersection of MacLaggan and Rattray Streets in downtown Dunedin, via the latter and then through the Town Belt reserve to its upper side in the suburb of Roslyn. It comprised a single-track line with two passing loops and used grooved steel running rails at 3 ft 6 in (1070 m) gauge. The route length was approximately 1.1 km with a maximum planned gradient of about 1 in 5. As typically used in the USA, the Roslyn cable ran in a concrete or brick lined tunnel beneath the roadway and midway between the running rails with line pulleys supporting the cable at regular intervals. The pulleys were supported on horseshoe shaped bent sections of rail line that also, via side brackets, maintained the gauge of the running rails. The narrow – 7/8" (22 mm) wide - slot for admitting the shank of the grip at the roadway level was formed from lengths of timber with replaceable upper edge pieces. See Figure 1. The 7/8" slot width chosen by Duncan matches that used by Hallidie for his pioneering Clay Street cable tramway [Bucknall Smith 1977]. Later cable tramways in the USA typically adopted a marginally narrower – 3/4" (19 mm) wide – slot, with the common objective being to avoid the risk of the wheel of a light horse-drawn buggy entering the slot whilst allowing enough clearance for the shank of the grip to pass through.



[Figure 1] Cable tunnel and rail cross sections. Part of Roslyn Tramway Co. drawing Sheet No. 1. (Toitū Otago Settlers Museum collection Ref No. 1976/39/44).

All the hitherto built cable tram lines in the USA were double-track lines, with single tracks only appearing in later years on some light traffic routes [Hilton 1982]. It seems likely that the initial adoption of single-track for the Roslyn line was done to reduce the initial cost in order to facilitate obtaining sufficient subscribed capital to float the Roslyn Tramway Company. In doing this, it appears that the initial Roslyn cable tramway was the first single track installation in the world. Figure 2 shows a Roslyn tram on the single track in a view looking down Rattray Street.

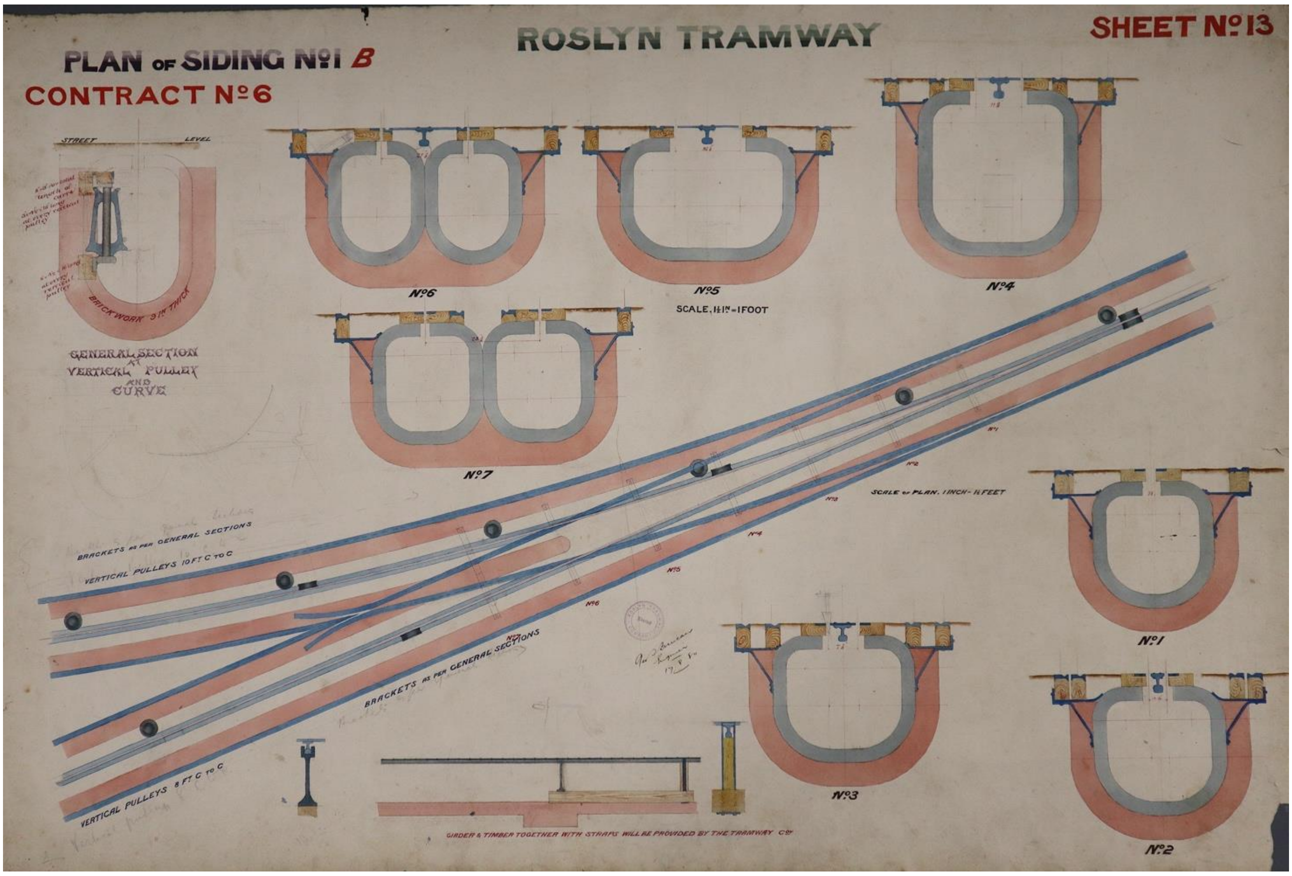


[Figure 2] Roslyn cable car on single track above the cathedral corner – F G Radcliffe (Auckland Libraries Heritage Collections Ref no. 35-R482)

The initial use of mainly single-track construction where the up and down running parts of the cables ran adjacent to each other in the single cable tunnel added operational complications. It also demanded arranging passing loops with track and slot points at each end of the loop to enable a sufficiently frequent service. At that time the use of cable tram points in the USA was mainly to reverse the cars at termini and for turn-offs into car barns. Two passing loops were provided on the initial Roslyn route, one of which was close to the Cathedral bend, with the upward and downward running cable separated into the respective parts of the passing loop. A double-sided grip was used to hold the appropriate up or down running section of the cable. The original Roslyn line was duplicated three years later in 1884 [Stewart 1997].

The contemporary cable tram routes in San Francisco were substantially straight and where curves were involved, they could be accommodated on reasonably flat sections, thereby allowing the use of so called 'let go' curves, the first of which appeared in 1880. At these locations the main cable or 'rope' was directed around a single large sheave on the outside of the curve and the gripman was required to eject the cable from the grip jaws immediately before the curve and then use the tram's momentum to coast around the bend before picking up the cable again on the far side of the bend. This was not practicable for the steep curve adjacent to St Joseph's Cathedral at the intersection of Smith and Rattray Streets where a grip car could not safely drop the cable out of the grip jaws [Ditchfield 1997; McAra 2007].

To solve the above problem, Duncan devised the 'pull curve' wherein the cable traversed the bend on a series of drum pulleys on the inner side wall of the cable tunnel. In this way, the grip could retain its hold of the cable, pulling the cable out from the drum pulleys as it passed them whilst the then tendency to bend grip shank sideways was resisted by rollers mounted on it that ran along a fixed 'chaffing' rail set immediately above the drum pulleys. This largely successful innovation was a world first that was later used on steep curves on cable tramways in the USA. Its downside was increased cable wear. Figure 3 shows the uphill part of the initial cathedral passing loop with drum type side pulleys. It also shows the upper side rail and slot points.

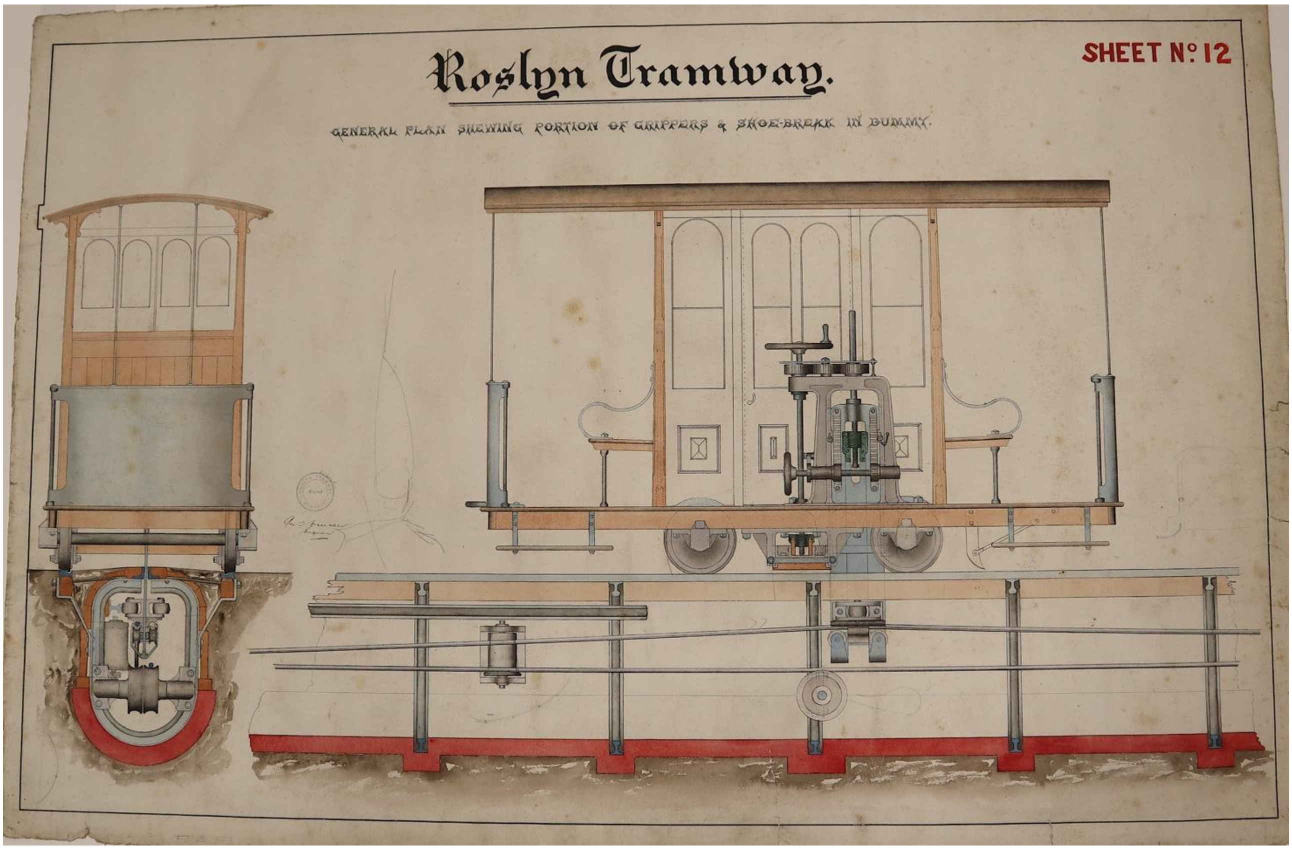


[Figure 3] Roslyn Tramway Co. drawing showing one side of passing loop track and slot points (Toitū Otago Settlers Museum collection Ref No. 1976/39/19).

The cable itself was imported, stranded wire-rope forming one continuous loop between the termini. For the initial installation, the cable was driven from an engine house at the Roslyn terminus above the Town Belt reserve, with a large sheave housed in an underground pit at the MacLaggan St city terminus. Power was provided by a Marshall semi-portable engine fitted with patent automatic expansion valve gear which reportedly could develop up to 40 hp (30 kW) [Ditchfield 1997]. The engine, via a flat belt, drove a pair of large diameter vertically mounted, rope driving sheaves, similar in principle to the practice for the San Francisco cable tram lines. Cable tension was maintained at first by placing the lower terminus rope sheave on a wheeled carriage within a brick pit with weights that hung over a well in the pit. This was later replaced by a similar principle but vertically mounted rope tensioning sheave running on a weighted carriage in the engine house that became the norm for cable tram systems. The cable, and therefore the trams, running speed was 6 mph (9.6 km/h).

Whilst there are some differing written assertions relating to the original cable cars, it appears from detailed and referenced research by Ray Hargreaves [Hargreaves c2000] that the three grip cars that operated when the Roslyn line opened in 1882 were made by Dunedin firms based on drawings prepared by George Duncan. Hargreaves refers to reports in the Otago Daily Times newspaper that indicate the first and second cars were built by Cutten & Co. with bodywork by Stansfield & White. The third car was reportedly of a ‘closed in’ design that was made by Cossens & Black. It appears that the initial braking provisions were limited to track or ‘slipper’ brakes that entailed pressing wood blocks down onto the rails. A report on a fatal accident that occurred on 23 April 1881 [Otago Daily Times (ODT) 20 May 1881, p 6], said that the upward-bound grip car lost its hold of the cable on the cathedral bend and accelerated back down the track crashing into the terminus, and that it was attributed to erroneous operation of the brake involving the closed-in third grip car. The report refers to the slipper brake being operated via a handwheel and screw mechanism rather than a lever operator as for the first two grip cars. In explaining the operation of the Roslyn cable trams, the same newspaper report refers to the grip in the closed-in third car being operated by a screw mechanism.

An early Roslyn Tramway drawing for a grip car with a closed-in middle section shows a handwheel and screw operated grip similar in principle to what Hallidie used on his 1873 Clay St line, but with an additional refinement that whilst releasing the grip jaws it progressively applied track or 'slipper' brakes and vice versa. A separate handwheel mechanism also enabled adjustment of the height of the cable grip. See Figure 4. It thus appears that this drawing was the basis for the closed-in third grip car that was made by Cossens & Black. Whist the report of the accident indicated that although the car turned on its side at the Maclagan St terminus, it was not seriously damaged and likely was repaired and returned to service. It is not known if the combined screw operated grip and slipper brake continued to be used. It seems likely, however, that in view of the accident it may have been abandoned in favour of lever operators as used on the first and second cars, and consistent with the practice on the then expanding development of cable tramways in the USA. Later grip cars on the Roslyn line were fitted with lever operators for both the grip and for slipper and conventional wheel brakes.



[Figure 4] Roslyn Tramway Co. drawing showing an early grip car with screw operated grip and slipper brake and part of cable tunnel with both a line and pull curve pulley (Toitū Otago Settlers Museum collection Ref No. 1976/39/45).

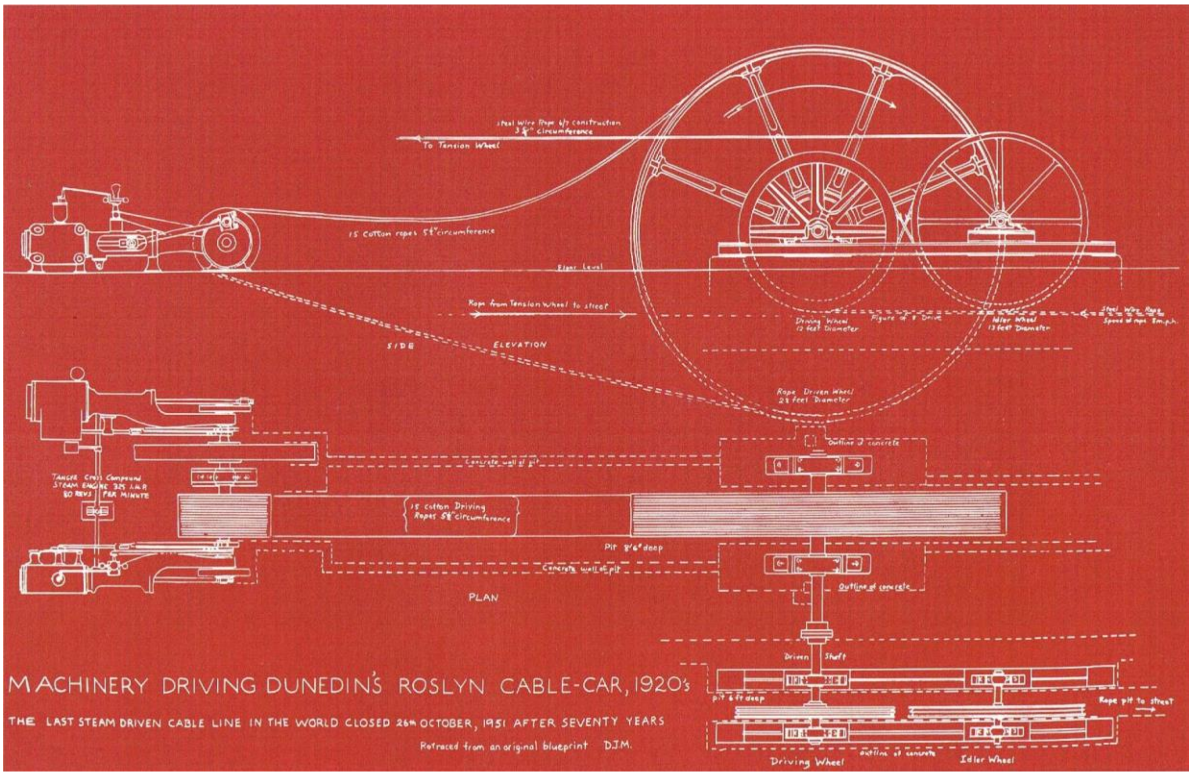
Ditchfield [Ditchfield 1997] conjectures that Duncan's invention of what was termed a 'Dolphin Brake' that via operation of a separate handwheel would force a wedge into the cable slot was in response to the above early accident. The same source asserts that it was fitted to the original Cossens & Black cable cars but that there is no record of it ever being used on the Roslyn line and that it was later removed.

The principle was however subsequently adopted on San Francisco lines that had particularly steep sections [Swan 1978].

According to Hargreaves research, the confusion that arose from references to cable cars being imported from America related to trailer cars which arrived in Dunedin in early 1881. The locally made grip cars were evidently fitted with hooks and chains to attach a trailer car, as had been the usual practice in San Francisco. However, soon after their arrival the trailer cars were deemed unsafe by the then Public Works Department (PWD) Engineer, C Y O'Connor, due to their height above the ground (presumably concern about a consequent high centre of gravity). As a result, only the grip cars were used for the initial operation of the line, a practice that then continued throughout the service's 70-year life.

In 1901 the Roslyn line was extended through several Roslyn streets and down into the Kaikorai Valley with the final terminal, engine house and cable barn being at Kaikorai Valley Road. Parts of this line had a gradient of 1 in 3.5 and permission to run passenger services over it was denied on safety concerns. This was eventually overcome in 1906 by the construction of a deep cutting through a direct easement where the maximum gradient was then 1 in 4.2, plus the addition of an emergency 'fell brake' to the cable cars. This entailed a flat bottom rail set up in the easement at surface level close to the cable slot. A set of jaws operated by a vertical handwheel in the gripman's compartment could be manually closed in an emergency to firmly grip the fell rail [Ditchfield 1968]. In the interim period the city terminus had been moved to the Rattray St intersection with Princes Street.

To meet increasing patronage demands, the driving machinery was upgraded in 1911 with a 325 hp (240 kW) cross-compound Tangye steam engine that was connected to the tramway rope driving sheaves via a multi-pass rope drive. See Figure 5. The cable speed was then raised to around 13 km/h. Two coal fired boilers supplied the steam requirement [Ditchfield 1997].



[Figure 5] Diagram illustrating the Roslyn line steam engine cable drive system from 1911 to 1951. (Courtesy of Don McAra)

The Roslyn cable tramway, was taken over in 1921 by the Dunedin City Corporation and operated for a total of 70 years, finally closing on 26 October 1951. At that time, it was the last steam driven cable tramway in the world.

Figure 6 shows a recently restored Roslyn line cable car reminiscent of the original enclosed third car made by Cossens & Black. Note the grip and brake levers and the vertical handwheel for the emergency fell brake that was installed after the 1906 Highgate to Kaikorai Valley Rd extension was opened.

[Figure 6] Restored Roslyn cable car at the Cable Car House, Mornington. Note Fell brake handwheel along with grip lever and regular brake levers. (Photo G M Browne, Sep 2021).

PART 2: MORNINGTON

Ian MacGregor

INTRODUCTION

Following on from the successful construction and operation of the Roslyn line, the Mornington Tramway Company was set up to transport people from the exchange in Dunedin's flat area which contained commerce, industry, wharves, and the railway station to the hilly residential suburb of Mornington. Two years later an extension to also hilly Maryhill was built. The Roslyn line's consulting Engineers – Dunedin's Reid and Duncans – were the Engineers for both new lines.

From the start the Mornington line had uphill and downhill tracks (tunnels/conduits) which was a big improvement on Roslyn's initial single line with passing loops and their intrinsic extra bending of the cable and extra points and pulleys maintenance.

The cable cars and trailers were efficient movers of people, and the system was used to move coal up the hill for use in the coal fired steam driven haulage system until replaced by electricity.
After tabulating basic information this part of the paper looks at construction, tunnel deterioration, cable problems, and the cable cars and trailers. Historic items, and operations including improvements and a possible world first are also covered.

Image interpretations are often presented as bulleted points. Extensive literature searching of newspapers, archives, and books, tend to be in diary format, with some conclusions nestled at the end of topics.

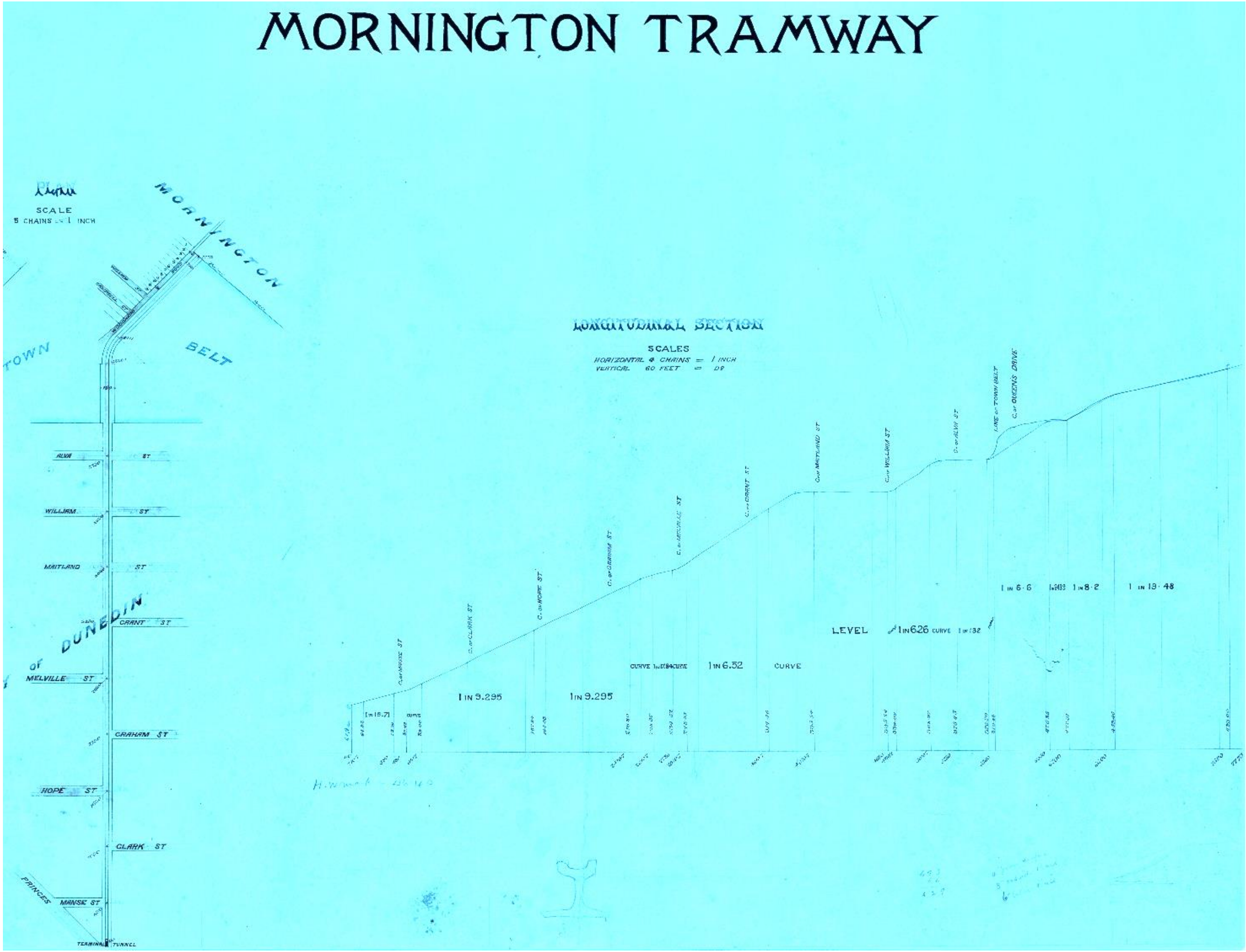
BASIC INFORMATION

- Gloriously opened 21 March 1883.
- Mornington Tramway Company (MTC) constructed and operated Mornington and Maryhill cable car lines.
- Mornington Borough Council (MBC) purchased the Mornington and Maryhill lines February 1903.
- Sometime between 1903 & 1916, reports became headed "Mornington Municipal Tramways" (MMT) not MBC.
- Dunedin City Council (DCC) took over the lines on 1 January 1916 when the MBC amalgamated with the DCC.
- Closed 2 March 1957.
- Cable: spliced length 11,500 ft. (3.5 km), circumference 3 ½ inches (90 mm). The cable ran continuously, with the cable cars gripping onto and off the cable to move and stop, unlike Wellington's two Kelburn cable cars which are fixed to the cable and so always counterbalanced.
- Cable cars operational at one time, max 4. For peak loadings each car could have an attached trailer.
- Maximum Number Passengers carried: Elastic!
- Route: From Exchange end of High Street, curving right into Eglinton Rd, finishing at Mornington terminus.
- 3 steepest gradients: 1:6.2, 1:6.5, 1:6.6. Vertical lift 450 ft. (140 m). Route length 1 mile (1.6 km). Rail gauge 3 ft 6 inches (1.070 m).
- Driving power:

- 1883 – 1901 Coal fired steam generating boiler 39 hp (52 kW) Speeds; initially 5, then 7, then 7.95 mph (8, 11 13 kph).
- 1901 – 1925 Steam engine + Peak load gas engine 22 hp (30 kW). Connection to a steam engine ½ min.
- 1925 – 1957 Electricity 200 hp (270 kW). Speed increased from 7.95 to 10.66 mph (13 to 17 kph).

STREET EARTHWORKS CONSTRUCTION

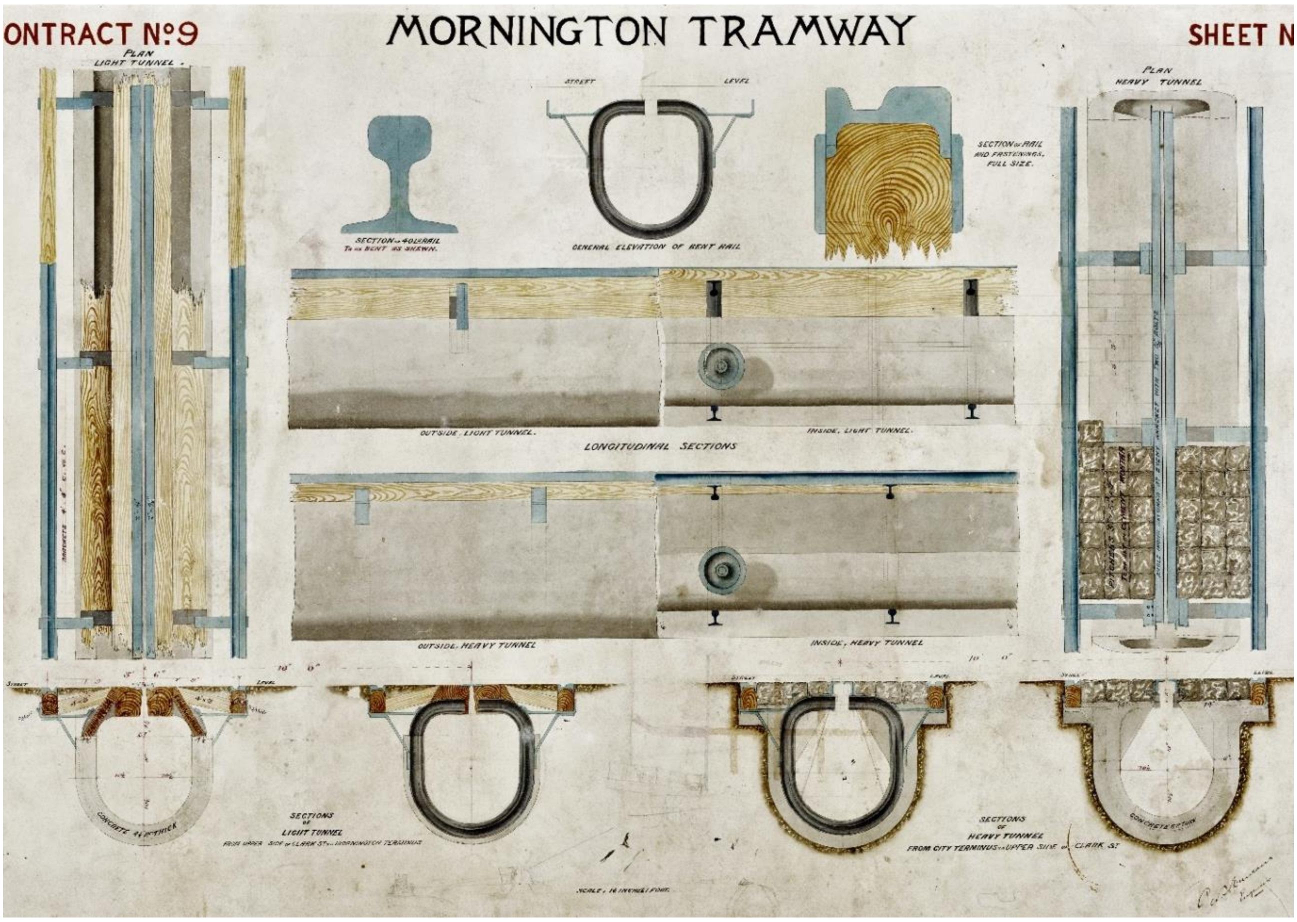
[Figure 7] Looking up High Street from the Exchange (In Princess St.,) and part of the Dunedin CBD. A big manual excavation is underway in the middle distance to form High Street. 20 years later, the Mornington Cable Car bottom terminus was positioned just above the upper pair of wheels. High Street, Dunedin, 1862. From the album: Early Dunedin, Meluish - Burton - Muir & Moodie, 1862, Dunedin, by William Meluish, Muir & Moodie studio. Te Papa (O.030520).



[Figure 8] Long section from the Exchange up High Street turning into Eglinton Road, finishing at the Mornington terminus. Drawing for Mornington Tramway, sheet no.1. John Reid and Sons Limited records, MS-3801/029/001 Hocken Collections - Uare Taoka o Hākena, University of Otago. Author cropped & photoed.

- Like many other drawings this one is not dated but the author believes it is 1882 in the light of other closely related dated drawings.
- In view of the 1862 earthworks underway in Figure 7, the author considers High St had been formed prior to cable car tunnel construction starting, apart from the cut at Queen's Dr (shown above, solid).
- No radii were located for the convex and concave curves.

TUNNEL CONSTRUCTION

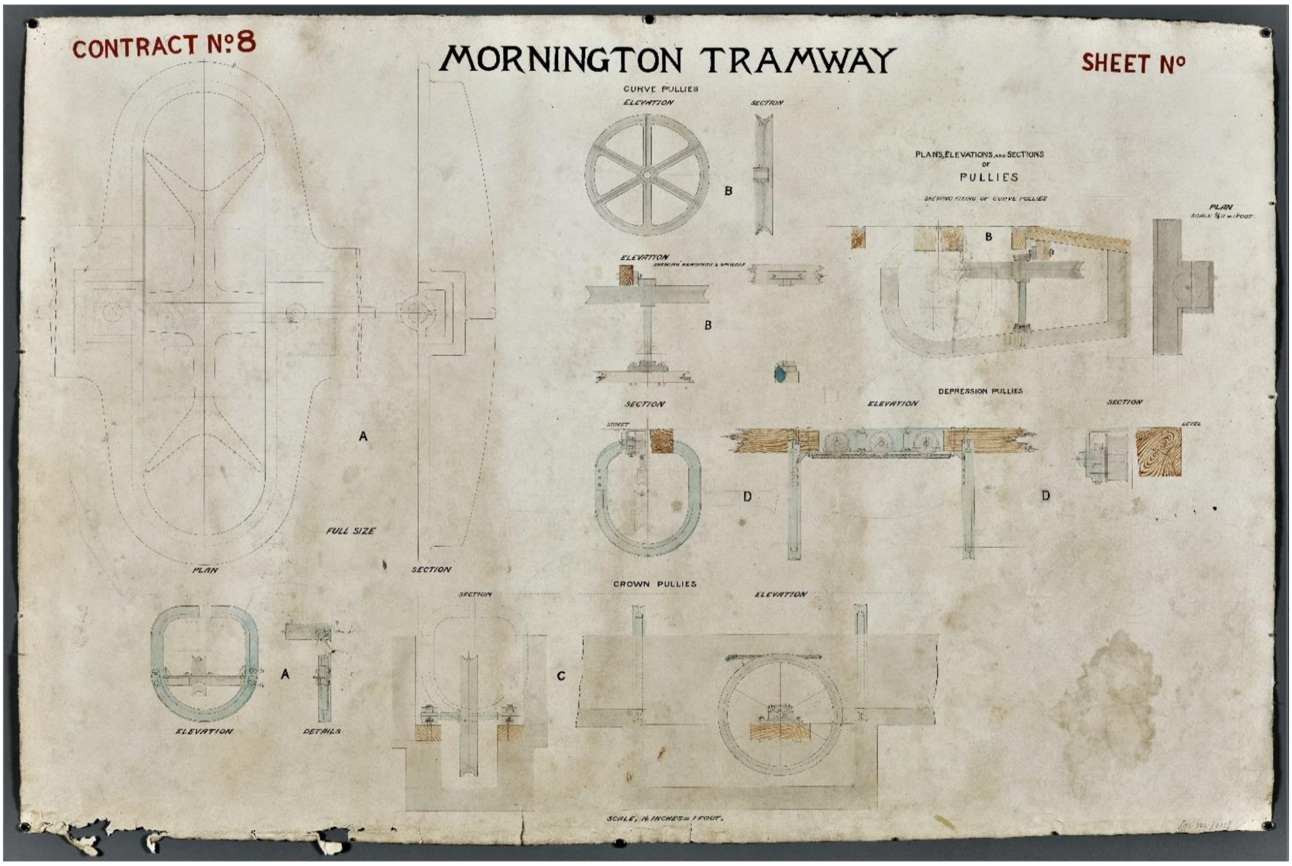


[Figure 9] The two Mornington Tunnel types: plans, cross sections, long sections. Drawings for Mornington Tramway, contract no. 9 (n.d.). John Reid and Sons Limited records, MS-3801/034, Hocken Collections - Uare Taoka o Hākena, University of Otago. Slightly cropped by author.

Construction features:

- Steel brackets made from bending rails placed at 4 ft 9 inches (1.2 m) centres supported 'cable carrying pulleys' at about 31 ft 6 inches (9.6 m) centres. [MS-3986/009]
- The road surfacing of cobble stones for the 'heavy tunnel' and gravel for the 'light tunnel'.
  Rails socketed into timber bearers.
- The amount of timber especially in the Light Tunnel. (This stunned the author.)
- No indication of the concrete being reinforced.

Tunnel Pulleys; for the cable to run over, around, or under.



[Figure 10] The four pulley types ('A' 'B' 'C' 'D') Which were mounted within the tunnels. Drawings for Mornington Tramway, contract no. 8 (1882). John Reid and Sons Limited records, MS-3801/033 Hocken Collections - Uare Taoka o Hākena, University of Otago.

[A] 'Cable carrying pulley' taking the weight of the cable in straight lengths of the tunnel.
[B] 'Curve pulley' at lateral curves. Normally several for 1 curve.
[C] 'Crown pulley' at convex curves.
[D] 'Depression pulleys' at concave curves. (Set of 3 pulleys in the 1 steel housing.) Examination of the right-hand section for "D" shows an oiling cap at the top of the bearing which looks very difficult to get at. The system was later changed to a grease cap on the end of the spindle [DCC. dwg R174A] The author saw the caps being filled several times and looked a much easier job than the earlier system would have been.

STATISTICS FOR THE THIRD CABLE RUN ON THE MORNINGTON LINE

Speed 8 mph (13 kph)
Distance travelled 161,330 miles (260,000 km)
Running days 1,241
Passengers hauled 1,516,747
Life 41 months

[*Evening Star*, 18 July 1890, p4]

It is important to appreciate such statistics showing the work done, and the huge number of passengers transported over tens of thousands of miles, up and down steep gradients, when reading of tunnel and cable problems.

TRACK DETERIORATION

There are numerous newspaper items relating to tunnel durability problems and the following three items indicate the scope and time range of what happened.

- The longitudinal sleepers on which the rails stood were originally put down in red pine timber and were later replaced by blue gum. In July 1893 the Dunedin newspaper Otago Daily Times (ODT) noted that some of the renewals were more substantial than the original work. [ODT 21 July 1893. p3] A few decades later the authoritative “Trees of NZ” [Cockayne L. & Turner P.] noted that Red Pine (Dacrydium cupressinum) “…cannot be employed in contact with the ground” and the author comments that the cable car tunnels were not the only example of faulty use of native timbers in engineering works.
- A 1903 letter to the editor of Dunedin’s Evening Star newspaper says “…. Anyone who carefully examines the line cannot fail to see where the rails in places are not only worn out but also split. The timber is done, and in some places, by the depressions in the line, the yokes which carry the rails and slot timber have sunk through the concrete tunnel. The tunnel also has in some parts rolled in its bed by the deviation of the line from the straight.” [ES 20 Apr 1903. p2]
- Also in 1903, the MBC purchased 50 or 60 old tram rails for repairing the Mornington line and reported it was necessary to keep 8 men employed mostly on surface and track repairs, but if the borough renewed the track and slot it would then have a line that would require little spent in the way of repairs for years to come. [ODT 12 Aug 1903. p6.]

So, by 1903, the track just 20 years old, had required major remedial work over the last 10 years; and “In 1910 the track was completely relaid.” [DCC. Archives. (a)]

The author suspects that, apart from the timber problem, the concrete forming the cable tunnels may not have been properly vibrated or had a high-water content when placed so hence weak, and /or may not have been placed against firm hard in situ ground, possibly caused by not removing all loose soil from the excavation.

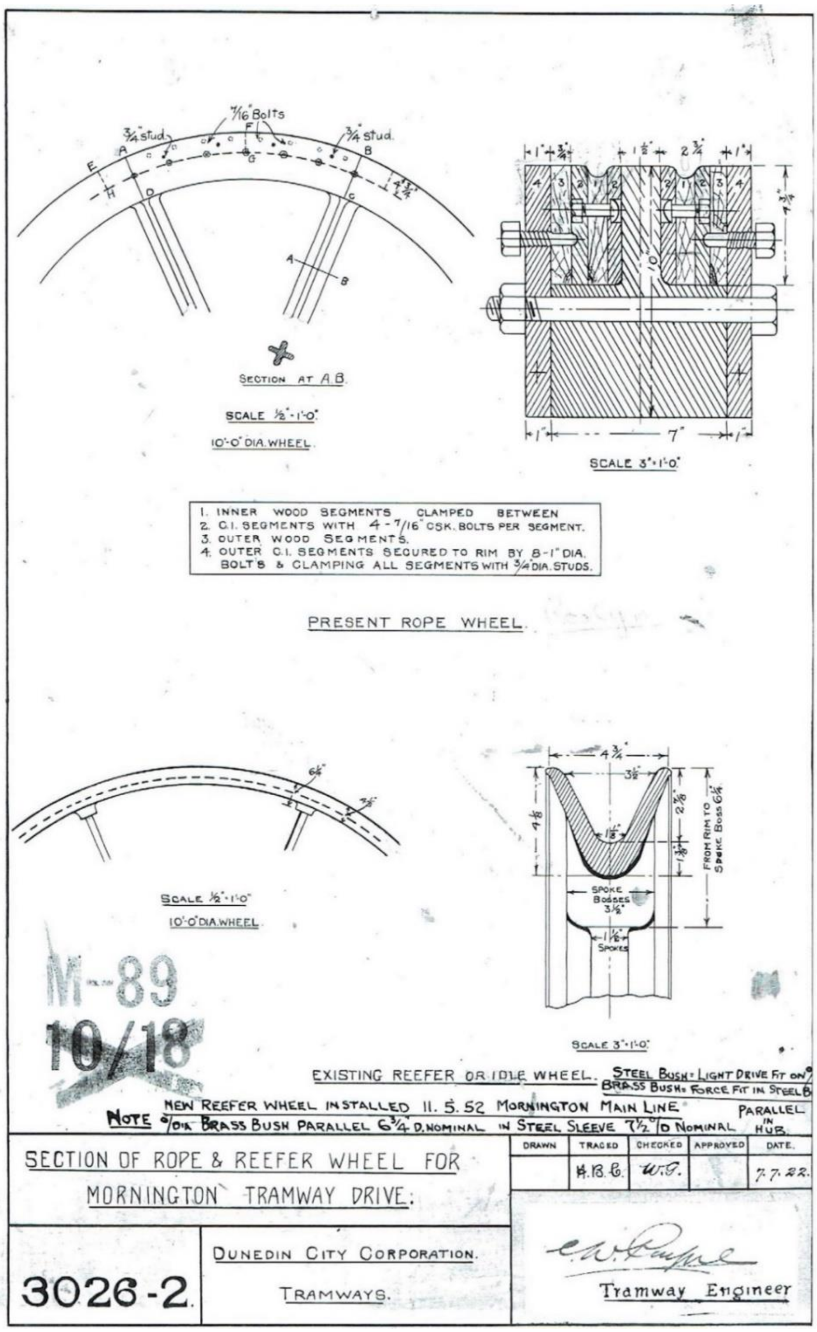
The track replacement seems to have cured the problems because there was virtually no mention of track items until the annual departmental reports for 1946-47, 49-50, 50-51, which variously described the track as being in reasonably good to excellent condition. [DCC. Archives. (b)]

So! Just how come when the author was at school he remembers reading or hearing that one of the reasons for not retaining the cable cars was that the track would have to be relaid? These reports support the author’s feeling at the time that there weren’t indications on the street that the track needed replacement.

However, on the bright side, lessons being learnt from Mornington seemed to have been put to good use in the 1900 design and construction of the Stuart St - Kaikorai cable car line where the slot construction used a steel “z” directly connected to the concrete tunnel, drainage and silt removal were specifically provided for, and at the road surface there was macadam between the wheel rails and the slot. “No wood is to be found in the permanent way and the maintenance bill will consequently be very light.” [ODT. 10 Oct 1900. p3. The Dunedin and Kaikorai Tram Company.]

But it was not only the (Mornington) track which had timber problems. In 1907, 32 ft (10 m) of timber under the rails of the tension carriage of the cable hauling machinery in the engine shed was replaced by jarrah timber. [ESD 10 Jul 1907. p12.] Fast forward nearly 1/2 a century and we read “Because of a momentary exceptional peak load, the rope (cable) slipped from the flywheel in the sheds and the resulting friction on the wooden inserts in the wheel set it on fire. The engine was stopped at once and the fire brigade called as a safety measure, but the fire was not serious. It was arranged to replace the wooden parts of the wheel during the night.” [ODT 3 Feb 1948. p4.]

Was it the wheel in Figure 11 below?

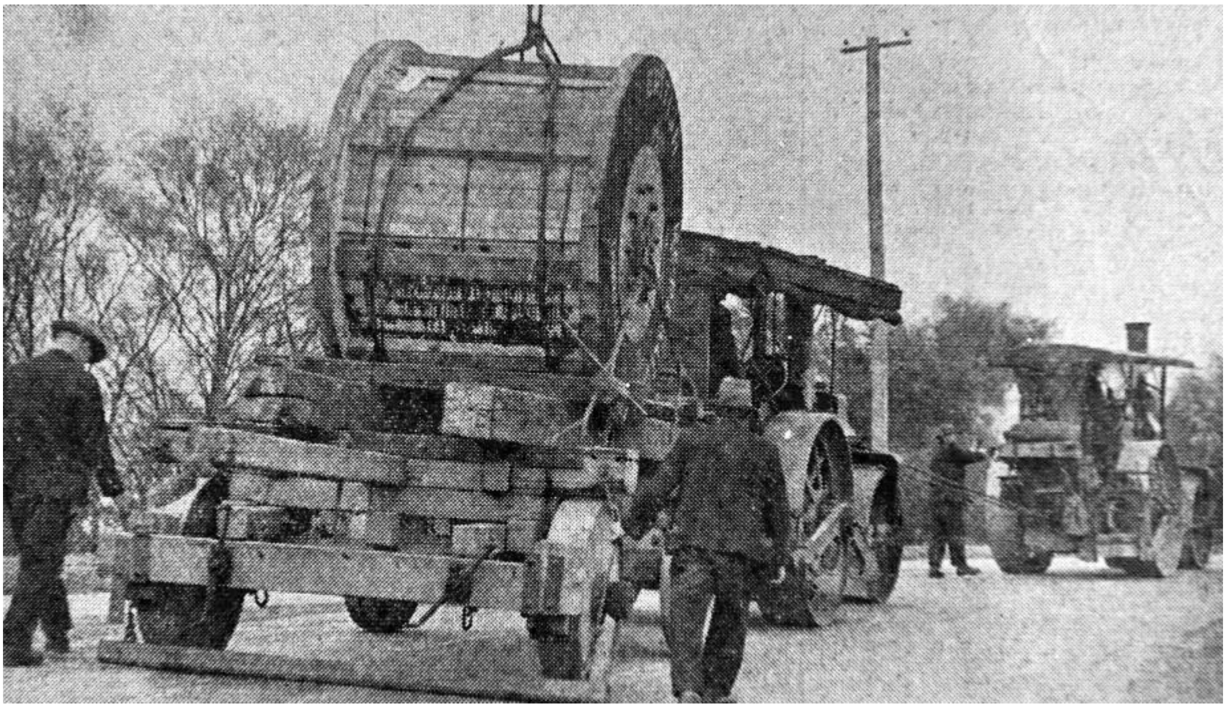


[Figure 11] Timber inserts forming parts of the reefer or idle wheel used in the Mornington winding gear. The wheel of the 1948 news item above? DCC. Archives. Transport Department Series List. M-89. Section of Rope and Reefer Wheel for Mornington Tramway Drive.

CABLES

Terminology

In the early days the term “rope” was used. However, the author prefers to use “cable” which today is understood to mean metallic and ensures no confusion with natural fibre or synthetic ropes.



NEW CABLE FOR MORNINGTON SERVICE.—Weighing 12 tons, this cable was drawn up the hill to the power house this morning, two steam-rollers of the Corporation works department being required to haul the load. This picture was taken just after leaving the upper end of Stafford street.

-

[Figure 12] 1938 Logistics. Evening Star 17 August 1938, p7. 12 tons (12 tonne) of new cable was hauled from the flat area of Dunedin up steep Stafford St to the Mornington Tramsheds for storage and subsequent cable repair or replacement which was done at night in the early decades and later on Sundays to avoid interrupting passenger services.

Cable Life

It had been hoped to provide a detailed list of cable types and lives but there are gaps in the information which was not helped by 3 changes of ownership of the lines (MTC, MBC, DCC) and at least 1 contradiction in available information. So the author has summarized his view of key points from reading a large number of ODT news items and Hocken Collections material as:

- Cable lives varied from 27 weeks to 43 months.
- Get and stay with a reliable and ideally proven manufacturer.
- Keep up to date with new technology but be wary of being the first to use it for cable car installations.
- Ideally it would have been good to keep a cable in stock due to the long time from calling tenders through shipping to arrival and then have the cable immediately on hand to go into useage when a cable deteriorated quickly or unexpectedly. This could easily mean storage for 12 months. But, Mornington experience was that a cable kept coiled on a drum for any length of time then gave a good deal of trouble.
- Have a good specification.

- Include a guarantee such as 48 weeks performance, and enforce it. In 1935 the DCC only paid out 30/48ths of the purchase price of a cable since it only lasted 30 weeks.
- Despite the foregoing, sometimes the purchase decision was made solely on the lowest tender, and in view of the great variability of cable lives may not have been economic decision making.
- Having the advantage of looking at 70 + years of records the author thinks that old lessons needed to get relearnt by the committees charged with the decision making. Carrying forward of past technical and economical lessons learnt is very important but sooner or later the lessons went by the wayside.

Cable problem: bunching

Bunching is when one or more individual wires of a cable break and bunch up around the cable.
When that bunch comes up behind a gripper, the grip man cannot release the gripper jaws from the cable. So the car is pushed relentlessly forwards. Scartezzini told the author this was a well-known problem. [Scartezzini C, 2020] Two case histories follow.

An ODT item during World War II said it had been impossible to obtain new cables from Britain or Canada and the DCC had been forced to take a US one for the Stuart St-Kaikorai line. It did not prove satisfactory. Whereas British cables did not usually bunch for about 12 months, the American cable bunched 9 weeks after installation and did the same again the following day. [ODT 12 Oct 1943 p4]

In 1956 a grip man could not release the cable on an uphill run and the car continued non-stop to the Mornington terminus where it hit another car. Damage was minor.

In such situations the standard procedure was for the conductor to jump off the car at the nearest signal box (a box on a power pole at the side of the road) and ring the engine room to get the cable stopped. But on this occasion the conductor had swapped over from the uphill car to work the downhill car. The author saw the grip man only system operating several times. His memory of this incident is bunching, which is basically confirmed by Campbell & Hargreaves [Campbell B. & Hargreaves R. p75].

Cable problem: Cable popping up out of the tunnel slot > Safer Operations

CABLE DAMAGED.—The surge in the cable following this morning's accident to a cable car at the bottom of the High street hill caused the cable to force its way through the centre aperture not far from the Maitland street intersection. The cable was cut and twisted, and will need to be spliced.

[Figure 13] The 1947 Cable Pop out. Caused by an Operational Mistake. Evening Star 29 January 1947, p6.

- With a slot width of 7/8 inch (20 mm) and a (new) cable diameter of 1.1 inch (30 mm) the force must have been big.
- Pop outs also occurred at Queen's drive between 1901 and 1921 [ODT 13 Jun 1913 p4. Incls 1901 ref], [ODT 9 Jul 1913 p8] [ESD 24 Jun 1914 p4], [ESD 19 Feb 1921 p6]. The July 1913 event might have been caused by temporary jamming of a kicker and the 1947 cause is explained below. No other reasons for pop outs were found.

The 1947 event was an operational "mishap" when the gripman failed to release the cable. At the bottom terminus where the track curved right the car jumped the rails and the trailer crashed into its rear. The cable burst through the tunnel slot and was damaged. Four passengers suffered cuts bruises abrasions and shock. The Chairman of the DCC transport committee said there was no equipment fault, there had been difficulty in getting experienced grip men, and that new men might have to be given complete training. Because of the shortage of grip men, the Maryhill cable car service might have to be discontinued. [ES 29 01 1947 p6] [ODT 1 Feb 1947 p6]

Eventually, following a consultation between the government's Public Works Department (PWD) and the Engineer-manager of the DCC Transport Department, a compulsory stop was instituted midway between William and Melville Sts to ensure the cable was running freely through the gripper and cars not propelled forward by bunching. [ODT 18 Apr 1947 p6]

Cable problem: Crown pulley shifted

In March 1913 another problem arose. A crown pulley at Queen's Drive shifted. [DCC. Archives. (c)]

Cable problem: speed increase

The 1925 increase in speed from 7.95 to 10.66 mph (13 to 17 kph) was considered to be a contributory factor in 2 cable breakdowns within 7 months.

Cable problems: possible causes

Apart from speed, the author considers possible causes of the preceding problems were firstly the rather large spacing between curve pulleys, secondly the close proximity of the necessary depression pulleys immediately downhill of the curve at Queen's Dr, thirdly pulley alignment problems, fourthly the major deflection angle changes at pulleys especially crown pulleys, and fifthly in some cases the cable type. If the 1910 tunnel reconstruction used the original or similar method of fastening curve pulleys to the tunnel as per Figure 10 detail B (the fixing of a timber packer to the upper timber frame) then fixing instability with time might have been a major factor. From a close study of drawings, and photos of the Mornington line in books [Ballment, Campbell & Hargreaves, Kenneally, McAra, Stewart], it seems as though there was only one crown pulley at each convex curve, and perhaps insufficient sets of depression pulleys at concave curves.

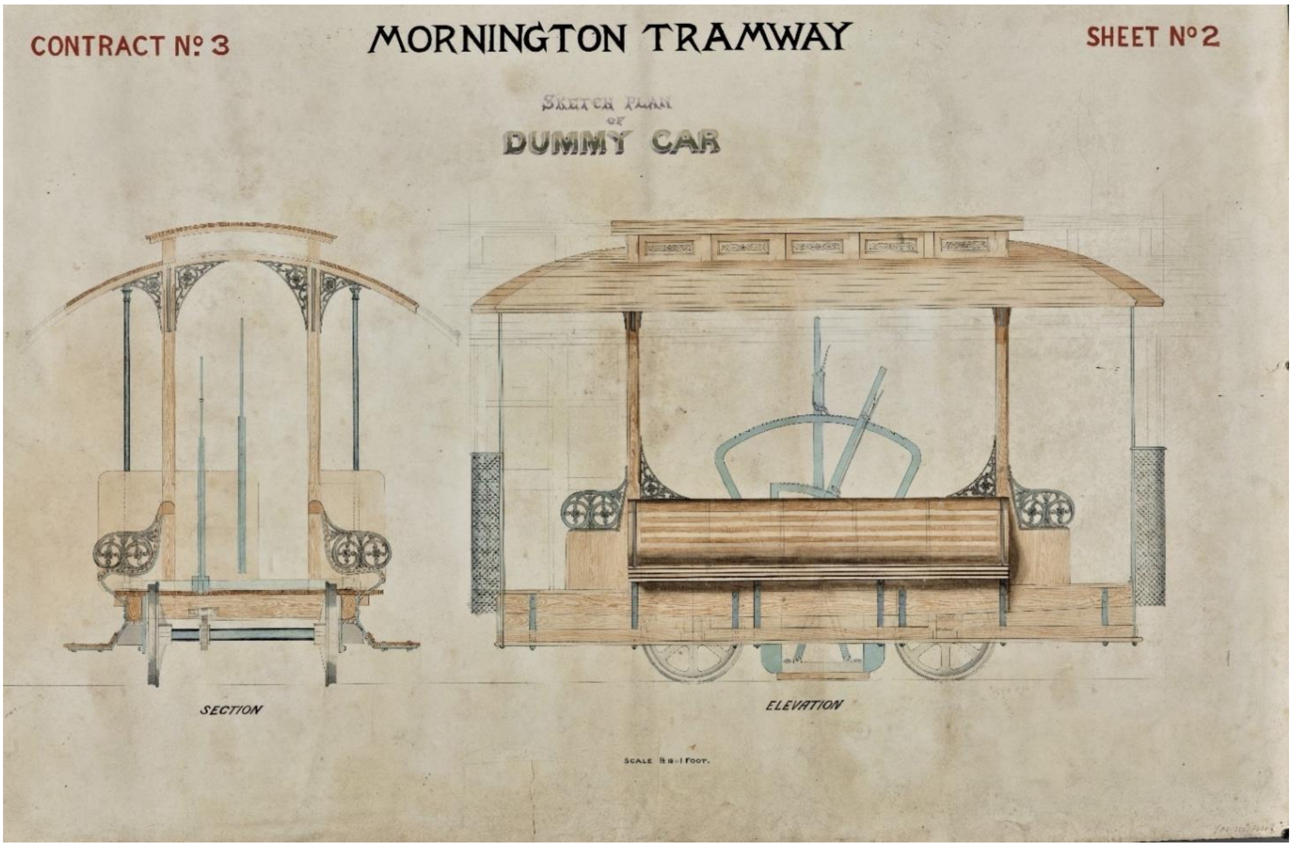
Pulley spacings must be limited to minimize the cable deflection angles at both horizontal and vertical curves to minimize cable problems. Two modern day references that would presumably achieve this are a limit of 4 degrees from cableway and lift company [Scartezzini C] or 4½ degrees as per a ski association guidelines. [SAANZ 2011.] To achieve this in the proposed re-establishment of the Mornington line it looks to the author's eye as though the radii of existing convex and concave street curves need to be increased. The photo below of a more modern system shows crown pulleys at closer spacings than on the Mornington line.

[Figure 14] Hyde Street Cable Car leaving Fisherman's Wharf area, San Francisco.
https://www.planetware.com/california/san-francisco-itineraries-for-travelers-us-ca-546.htm#:~:text=Hyde%20Street%20Cable%20Car%20leaving%20Fisherman%27s%20Wharf%20Area
Closely spaced crown pulleys - under the manhole covers.

CABLE CARS & TRAILERS

Terminology

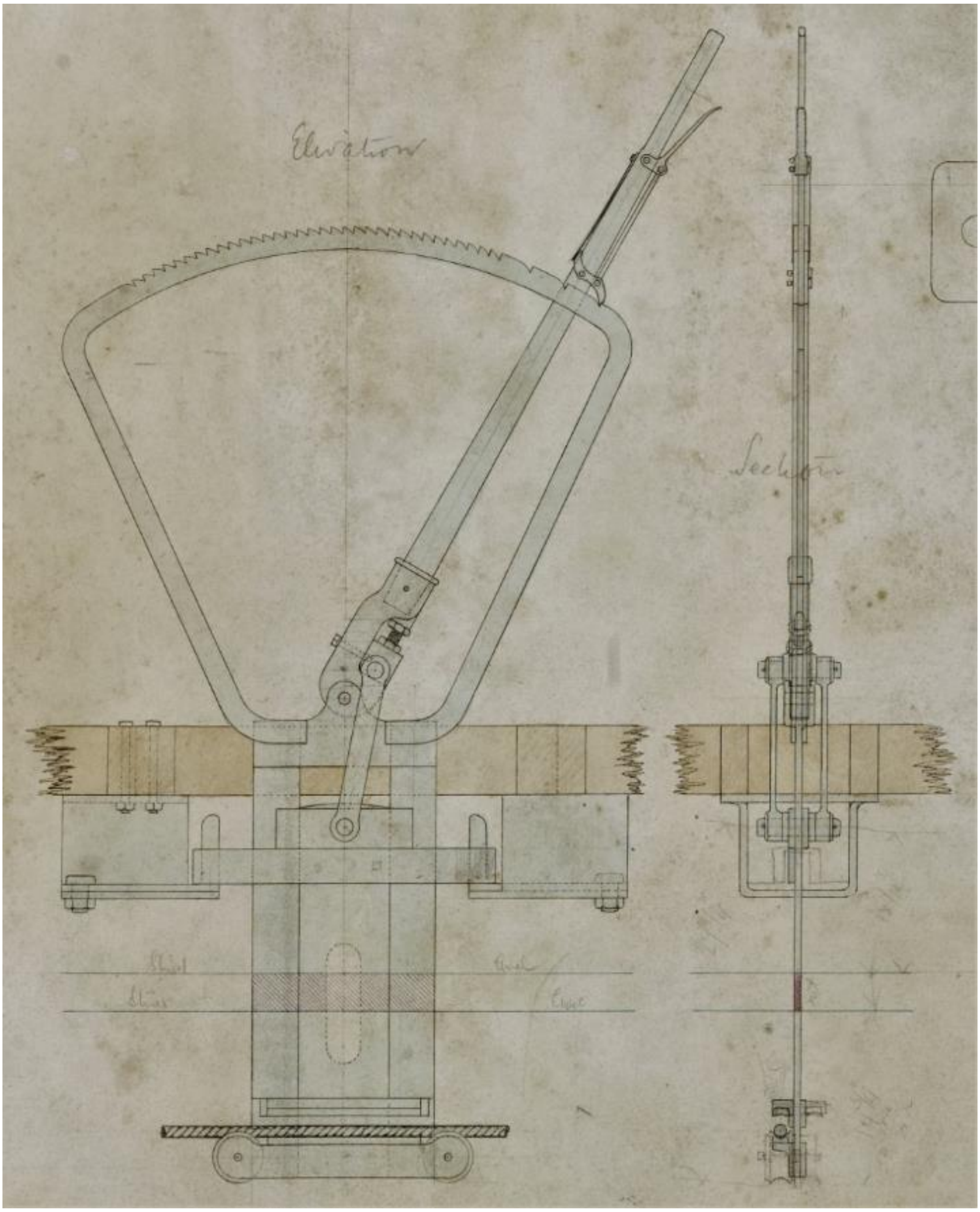
Figure 15 below contains the term 'dummy' which is used extensively in the early decades. 'Dummy cars' was also used. The author prefers and uses the later name 'grip car', and sometimes cable car – as used in his era.



[Figure 15] The drawing for the first Mornington Grip Cars. Drawing: Mornington Tramway, contract no. 3, sheet no. 2. John Reid and Sons Limited records, MS-3801/031/001 Hocken Collections - Uare Taoka o Hākena, University of Otago.

- The first Mornington cars were constructed to the above design, built by the Dunedin firm Cossens and Black, then tested on the Roslyn line, and "found to work admirably their gripping power being all that could be desired." …. "It is proposed to travel at the rate of 7 mph (11 kph) – a quicker speed than that maintained on the Roslyn line, which is only 5 ½ mph (9 kph) [ODT 8 Feb 1883 p2]
- The glass clerestory windows seen in the roof remained a feature of later cars although covered about 1920 to stop sunlight which sometimes blinded grip men's vision. [McAra D. 2021]
- The bigger lever is the gripper lever which operated the 'centre gripper plate' and its 'jaws' containing 2 soft metal 'dies' which clamped onto the cable (Figure 16). Normal die life was 4 weeks but in December 1889 when a new cable was installed the dies only lasted 4 days during the first few months of that cable which also cut down all the old pulleys [ODT 18 Jul 1890 p3]
- The smaller lever operated the 'slipper brake' which directly forced onto the rail a block of wood - seen above the word "elevation".

- The section looks directly into the 'grip man's well'. Later, with an extra brake lever, there was not much room for the grip man to pass the levers when walking between well ends.



[Figure 16] The Gripper. Part of: Drawing for Mornington Tramway Extension, contract no. 3, sheet no. 4. John Reid and Sons Limited records, MS-3801/031/002 Hocken collections - Uare Taoka o Hākena, University of Otago.] [Undated] [Author cropped.]

- Below the hand grip the thin black strip is a steel flat which was the "spring" keeping the pawl in the ratchet and later replaced by a spiral spring.
- Brown, floor of grip man's well.

- Centre Gripper Plate size: 5/8 x 8 inches (16 x 200 mm) [DCC. Archives. (d)] Slot width 7/8 in (21 mm)- gaps to edges only 1/8 inch (3 mm).
- The force from the cable went via gripper plate yoke & collars to 2 pins whose excess internal diameter allowed the gripper plate lateral movement to cope with variable slot positioning.

[Figure 17] Grip Car (basically as per Figure 15 drawing), and Trailer. Author Identified as pre ≈ 1900 and at Queen's Drive. Nelson Provincial Museum, Bartel Collection: 324213. [Author cropped].

- Grip car
  Features identifying the date
  - The short length of the cabins. Lengthened early 1900s [Stewart G.]
  - The rounded ends.
  - No door into the narrow cabin.
  - The small square windows at the ends. (Initially no windows at all, just open ends.) These changed after February 1903.
- Trailer
  Trailers were connected to cars at peak loading times substantially increasing carrying capacity.
  Note the distinctive pre 1903 style with the high rounded roof and advertising.
- Right hand running
  The car and trailer head downhill to the city terminus (trailer at rear), but are on the wrong side of High Street because this was in the days of right hand running. The uphill line can just be seen in the foreground.

[Figure 18] Grip car 101 and trailer ascending High Street. Photo: G Stewart, July 1956.

- Car 101 was the standard type used after February 1903 (apart from temporary cars) until close down. A big improvement on the original ones, being now enclosed, with double the amount of seating, and wide sliding doors.
- No standing passengers in the front cabin because that obscured the grip man's vision – a PWD requirement [PWD 1911 report]. Sometime after 1903 the then five windowpanes were changed to the 3 as seen, again improving the grip man's vision.
- Above the passengers' heads are leather straps for passengers standing on the running board to hold. The conductor also held onto a strap (with one hand) while collecting fares with the other.
- Front of car, bottom centre: The round steel buffer matched the corresponding buffer on the trailer and took the trailer's weight when going downhill. Left of the buffer is the connection for the trailer, enabling it to be towed along the flat parts of High St. To disconnect, the conductor just leaned forward from the trailer's leading platform, pulled the pin - and rapidly applied the trailer's brakes.

Elastic passenger capacities

To cope with crowds during the 1889-1890 Dunedin South Seas Exhibition 2 trailers to 1 grip car were run. However, safety was questioned and the PWD banned the practice. [Campbell and Harris p16]

The PWD reported that the DCC licensed maximum capacities were Mornington car 38, trailer 31, and said "…there are many trips a day when the number carried is over 60…and occasionally I believe over 80." He had seen over 60 people on the grip car alone. [PWD 1911 Report]

During the 1954 Royal Visit "The greatest feat of the day was that of the Mornington Cable Tram which left the city that afternoon…with 201 passengers on car and trailer and what's more it took the combined efforts of 2 grip men to get the car started. No doubt 1 grip man could have handled it but as a grip man off duty at the city terminus saw what a struggle he was having he hopped aboard and gave him a hand." [Ditchfield G 1954]

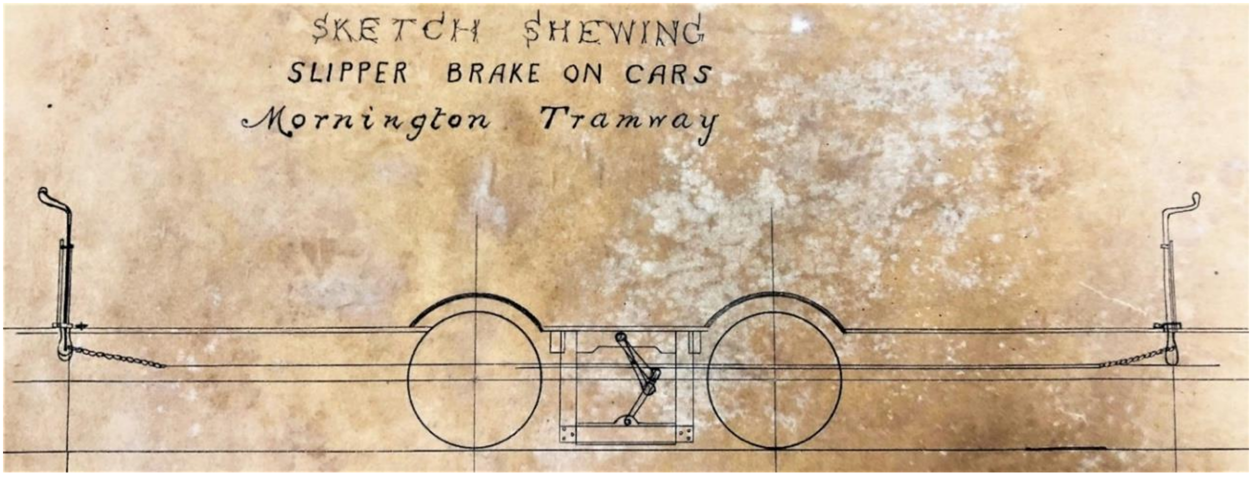
BRAKES

The authors contend that originally there was just the set of slipper brakes on the Mornington cars, with the ratchet, and the wheel brakes coming later. Slipper brakes were used on trailers as well as cars.

Brakes – slipper

Terminology

In Figure 19 below note the term "cars" standard in the 1880s when referring to trailers, the term of at least the 1940s and 1950s, and so used by the author.



[Figure 19] The Basics of the slipper brake as used on trailers. 'Sketch shewing slipper brake on cars'. John Reid and Sons Limited records, MS-3801/036/003 Hocken Collections - Uare Taoka o Hākena, University of Otago.

The slipper brake was operated by the conductor rotating the 'goose neck brake handles' at an end of the trailer. It looked hard physical work. At floor level, a ratchet and pawl to stop the brakes unwinding were operated with the conductor's foot. Below the floor a chain wound around a tapered shaft partially straightening the 'elbow' seen between the wheels hence braking directly and very beneficially onto the ground. The PWD 1911 report noted that trailer slipper brakes "should" be fitted with 'sanding apparatus'. From the author's examination of photos and discussions with Don McAra [McAra D 2021] it's concluded that this was not done.

[Figure 20] The uphill end of trailer 109 shown sitting on the 'trailer siding' which was at right angles to the Mornington terminus. Photo: G Stewart, October 1951. [Author cropped]

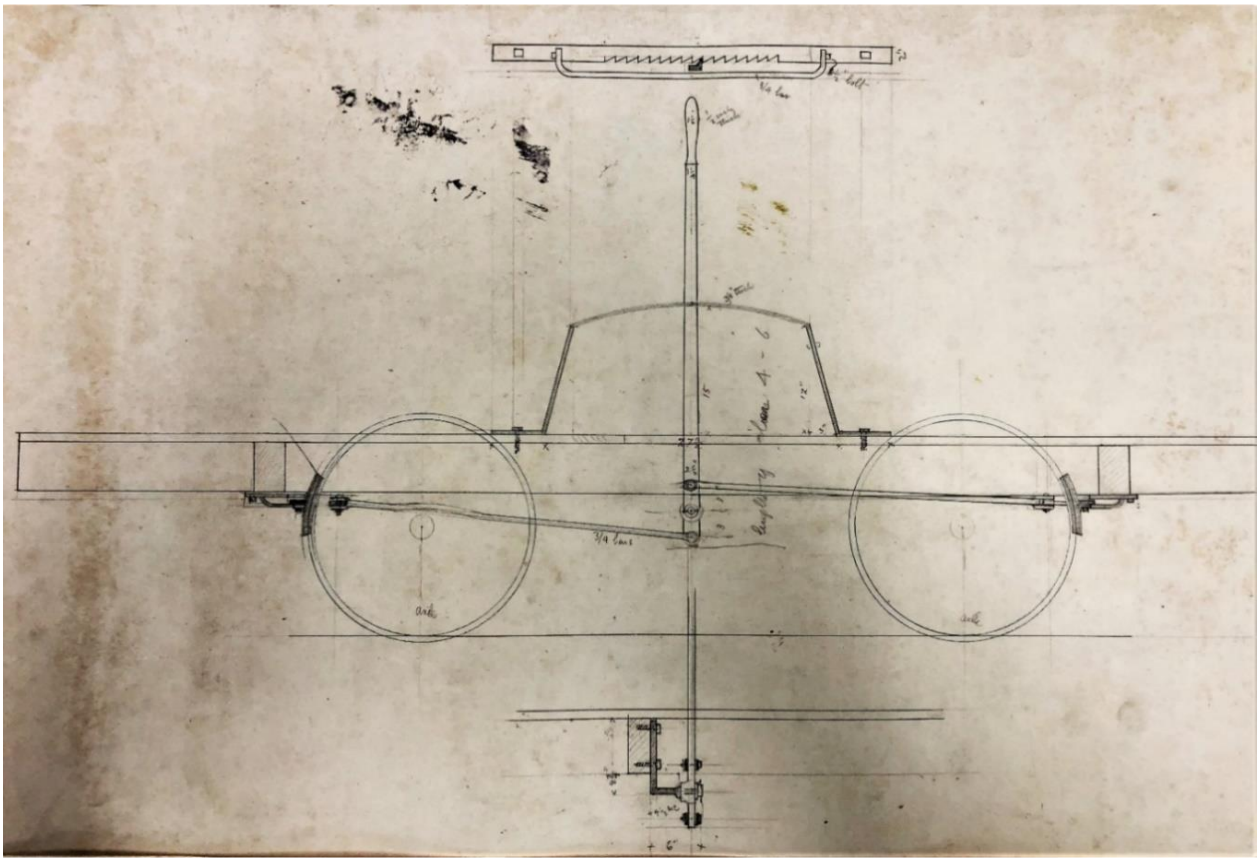
- The slipper brake parts can be seen in 109 just as in the 1880s drawing. No real change in 70 years.
- Just below the trailer platform in the centre is a rectangular steel box. The conductor swung it out and connected it to the back of a cable car for uphill travel.
- To the right of the right brake rod is a chain and hook which correspondingly linked to at the back end of the car and was an automatic brake if the main connection between the two broke. It could also be applied by the grip man.
- High above the platform on the right is a black triangle, lever, and a rod going down through the platform floor. At the top terminus, before disconnecting the trailer from the car the conductor would work the lever to set the pawl off the axle ratchets (refer below: brakes – ratchet) thus disconnecting the automatic brake.
- Under the roof, notices banning passengers on the leading platform were instituted in February 1947. [ODT 4 Feb 1947 p4] Nothing new! District Engineer F. W. Furkert said in his PWD 1911 report "…also no standing should be allowed on at least one platform of the trailer…" The author says it's a very important rule because the conductor commonly transferred from the grip car to the platform while the combination was moving. And it was a big stretch between the two. In an emergency it was vital he got onto the leading platform very quickly and with free access to apply the trailer brakes. The author remembers the rule as being well followed.

See the above and more today on trailer 111 in the Dunedin Heritage Light Rail Trust's 'Cable Car House' in the centre of Mornington.

Brakes – wheel

In Figure 20, wheel brake shoes are just discernible on the outer sides of the two wheels, and are shown schematically in Figure 21 below. Later grip cars had brake shoes on both sides of a wheel but the trailers only on the outer sides.

Brake shoes working onto the wheels were applied by a third lever in the grip man's well. Their introduction date was not found but were certainly in use by 1895 when an Otago Daily Times editorial adversely commenting on the operation of the Roslyn cars following an accident, said it was the Roslyn directors' duty to install wheel brakes as per the Mornington Company's line [ODT 24 May 1895, p2]. The drawing below is undoubtedly for the original design, and an identical looking application lever can be seen in two photos in "Fares Please" [Stewart G. p156]. The lever and quadrant of the much larger and heavier later design shows in Figures 15 & 16.



[Figure 21] A Sketch of early wheel brakes with a simple quadrant. Untitled undated drawing signed by Duncan. MS-3986-009 Hocken Collections - Uare Taoka o Hākena, University of Otago.

[Figure 22] Underneath the Maryhill Car 106, Built 1906. [Photo: On location at toitū Otago Settlers Museum. MacGregor I. D., Jun 2020.]

- Behind the left wheel two downward facing steel channels held the slipper brake block of wood.
- Sanding pipes in front of each wheel allowed sand onto rail. Activation was by the grip man and still works today.
- Built with all 3 braking systems. Sadly today, the wheel brakes are missing.
- Photo front centre: 1 of 4 tapered cantilevered longitudinal structural beams. The tapering helped with ground clearance at concave curves, and a wee lightening of the dead load.

Brakes – Pawl and ratchet

[Figure 23] Don McAra holds a Pawl (gray) into a Ratchet in the 'Tramways Historical Society Tram Barn and Workshop', Ferrymead Christchurch; where Mornington Car 103 is being restored. Photo: ID MacGregor, August 2021.

- Grubscrews fix the ratchet to the axle. Visible on the rear axle when you enlarge the photo.
- Original conventional keyways were used on Maryhill car 106 where one keyway went the length of the axle holding
  the wheel and adjacent ratchet at each end of the axle.

An undated Hocken Collections sketch [MS-3801/036/002] for a pawl and ratchet car brake contains text saying "This rod runs through a sheath formerly used for shutting doors." which confirms that the pawl and ratchet were a later addition to the cable cars' braking systems.

Brakes – 'Automatic Pawl Gear'

In June 1910 the PWD wrote to the Mornington Borough Town Clerk pointing out that they had previously required that "trailer cars must be provided with adequate braking appliances, and that in addition to the conductor on the motor a similar officer must be on the trailer, and should not leave his car on any account between the termini, in order that he may be on hand to instantly apply the brakes if required." [DCC. Archives. 2235]

In August 1910 a further letter from the PWD [DCC. Archives. 2261] referred to unsatisfactory trailer brake tests and when could further testing be done. The letter also asked for details of their proposals to run the trailer without the extra conductor and for a tracing showing the proposed combined braking gear.
Then finally in 1911 we read “all the dummy cars and trailers were equipped with the automatic pawl gear, and it is giving the utmost satisfaction”. [ODT 16 Feb 1911 p10.]

A few weeks later, the PWD 1911 report noted that the “The braking gear on the gripper is of ample power...”

No further references to a second conductor were found, and it seems that with a braking system workable from cable car and/or trailer, the second conductor requirement went away.

MISCELLANEOUS HISTORIES

1903 Tramshed Fire. Cable Patching. Temporary cars. Opportunistic Improvements / Maintenance

Early in the morning of the 9th February 1903 fire destroyed the tram shed, destroyed all cars, all trailers except no 107, and destroyed 3 adjacent houses. [Campbell and Hargreaves p25 ff]. The boiler and driving equipment in the basement floor of the tram shed were not too badly damaged and were repaired.

Part of the Mornington cable was burnt in the fire and replaced with a portion taken from the Maryhill cable. Then to make up for the stolen Maryhill length plus replacing the burnt Maryhill length a new length of cable had to be procured from Sydney! [ODT 23 May 1903 p2.]

Then on April 24th a team of horses hauled to the bottom terminus a temporary roofless car Dunedin built by Glaister and Carey. Steam was turned on for the first time since the fire and after some adjustments to the gripper the car moved up the hill at about 5 mph (8 kph). Carrying capacity was 30 to 40 passengers. [ODT. 1903 Apr 25.] Roof coverings were fitted some days later. [ODT 29 Apr 1903 p5]

During the 2 ½ months stoppage opportunity was taken to make the following improvements:

- Electric signal bells and telephone for communicating back to the engine room were installed on poles at the footpath edge
- Slots which had closed in many places were opened and stayed back to the yoke brackets. Consequently the gripper then passed through the slot easily and there was an absence of sudden checks to descending cars.
- The tunnel was cleaned out with over 50 wagon loads of mud removed.
- Drains which let water escape from the tunnels were also cleaned out. [ODT 29 Apr 1903 p5]

Hooking and grip men's comfort

[Figure 24] Neville Jemmett (Chairman: Dunedin Heritage Light Rail Trust) holds a Cable Hook, inside the Trust's Cable Car House at Mornington. Photo: ID MacGregor, June 2020.

- Before departing some termini, the hook had to be inserted down through the slot and the cable pulled up into the gripper. Short hard work.
- The 2 wind shields (beige colour) were fitted to one side of the grip man's well to stop wind and rain going through. Not introduced until June 1913 they were "much appreciated by the drivers". [DCC Archives (e)]
- At the bottom, oval openings enabled the grip man to collect fares from outside passengers if no conductor.

Night lighting

[Figure 25] A Kerosene Headlight from the exterior of a Roslyn Car. Photo: ID MacGregor, April 2020. Courtesy D McAra, Ferrymead.

- A second kerosene lamp hung in the grip man's well with some light going through to the passenger cabins and fumes escaping through the roof vent one of which is seen in the foreground of Figure 23. No vent can be seen in Figure 15 nor in a photo taken just after the Roslyn line opened [Stewart G p144] and the author believes the vents were added shortly after the first cars were built. Vents are seen in numerous photos where they remained as a form of decoration until the system closed. [McAra D, 2021]
- The 1921-22 Annual report [DCC Archives (f)] recorded that the kerosene lamps were replaced by 6-volt lighting from an Edison battery recharged daily, that the electric lighting was a decided improvement, and they were looking at improving the headlights. A battery is in the restored Roslyn car in Cable Car House, Mornington.

Terminus Changes

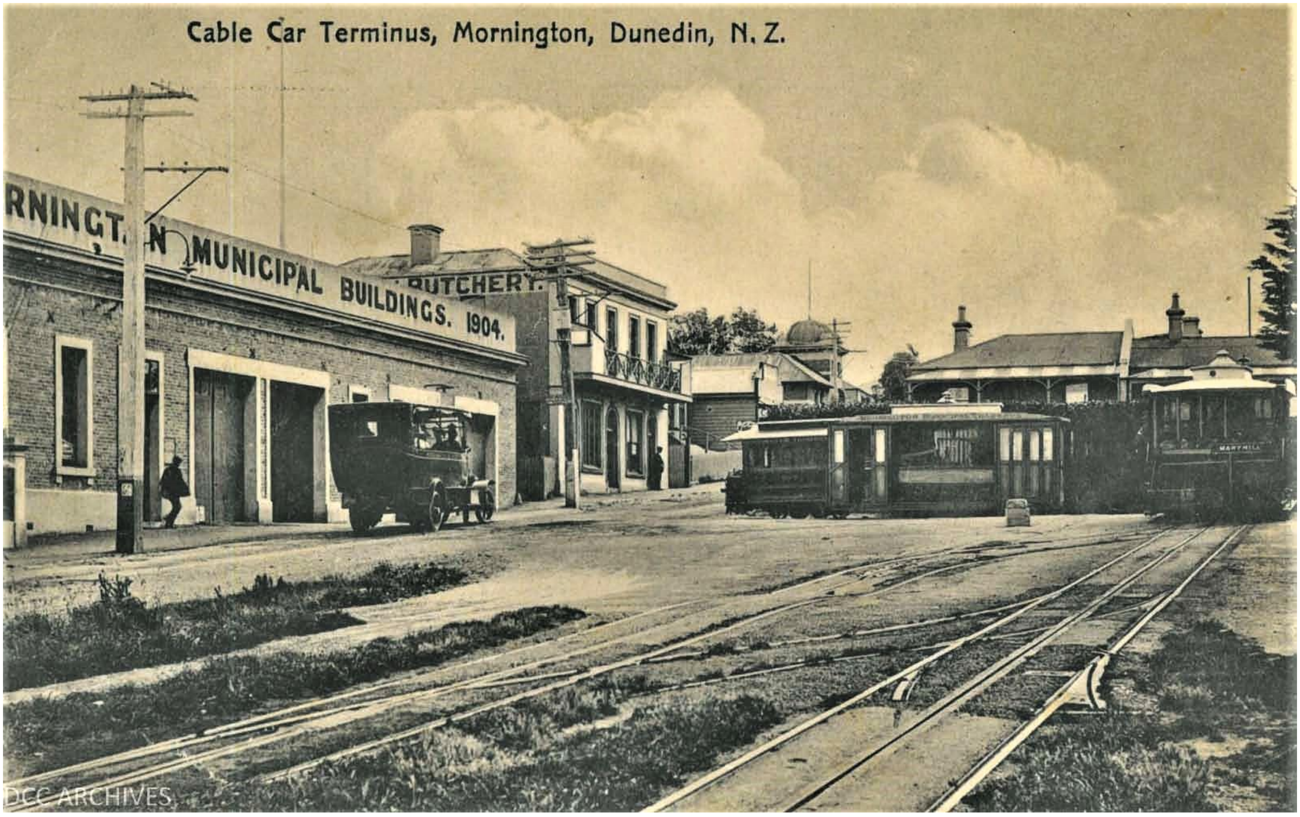
Swapping the car from the uphill to downhill line:

At the Mornington terminus, between August & Oct 1889, a labour-intensive operation was changed to a gravity one. Originally the up going cable car had to be pushed onto a turntable. The car and turntable were then manually pushed around about an eighth of a circle, and the car manually pushed off the turntable, from where it ran under gravity on the down line.

The new method had the car stopping short of the turntable, running back down under gravity through new points and a short length of new track onto the downhill line. Much labour and time saved. The new operation was called the 'loop line' in the MTC's Annual Report [ES 18 Jul 1890 p4], and elsewhere (confusingly) 'the shunt'. (Ref Figure 26 below).

Automatic cable connection

In 1888 Tramway Engineer Lowden constructed a dip (seen below, Figure 26) near the top of the down line allowing the cable to be automatically fed into the gripper. [Details, Stewart G. p202] Previously it had had to be hooked up into the gripper manually. Another labour and time saving technique. And Dunedin producing another world first?



[Figure 26] The Mornington Terminus looking up Eglington Road and into Mailer Street during the brief period the Char-a-banc ran - Nov 1912 > mid 1914. The system was still right hand running and so downhill is the left line. DCC. Archives. 15015486069. Flickr.

- The char-a-banc (bus) replaced the short-lived Elgin Rd cable car line but was not a success, breaking down shortly after inauguration and then getting worse. It also ran along Glenpark Av in lieu of some Maryhill cable car services and damaged the track. [Campbell and Hargreaves p34-39.]
- On the left, behind the big closed double doors was the cable storage into which the drum of cable in Figure 13 had to be reversed by one of the towing steam rollers.
- In the centre a trailer can be seen behind a cable car, and is being temporarily held on a length of old Elgin Road line until retrieved for a lunch time or evening peak load. The car itself is stored on the line running from the turntable (behind the right most car) through the open doors and into the tram shed.

- In the right foreground a short pair of rails swing right – ‘catch-points’ – which the PWD [DCC, Archives (g)] had required to divert any runaway trailer from careering off down the up line.
- Before going back downhill, the cable car (extreme right) had to be positioned ahead of its trailer, so it ran down under gravity through the upper points onto the left most track (as photo viewed), in the dip picked up the cable, and stopped two car lengths below the points at the lower left. The trailer having been towed uphill (right hand track) and temporarily stored between the two sets of points, was then - under the conductor’s control - run down through the bottom points and across via the trailer track (no slot) to behind the car and connected up; and hey presto off for more happy passengers.

Right hand to left hand running change

In 1928 changes were made at both terminals to convert from right hand running to New Zealand’s left-hand side of the road driving. Duncan had thought that New Zealand would change to the American right hand driving system and so designed the Mornington and Maryhill cable car systems that way.

[Figure 27] Mornington Terminus looking down Eglington Rd. A Car and Trailer Ascending at the Right. Descending Trailer (and car) at Left, both on Reserve Land and not a Street. G Stewart, October 1951.

- Front left corner, track remains from right hand running:
  - Between the steel plates and sliding underneath, a ‘kicker’ spans the slot.
  - When the grip car came uphill its centre gripper plate moved the kicker right. Once past, a spring pushed the kicker back left. Then on the journey back the kicker ensured that centre gripper plate curved right into the slot of the downhill line.
  - In some places a kicker’s function was to prevent the cable coming out of the slot if there was a malfunction.

- Between the two cars and on the downhill line are two white zones which are sections of the tunnel rebuilt in the late 1940s or early 50s in (heavily?) reinforced concrete to form a turning circle for Elgin Rd and Belleknowes buses and to the best of the author's knowledge totally survived the heavy bus loadings. The turning circle allowed the buses to turn round, go back up the street and pick up passengers on the far side of the street outside the tramsheds just out of view on the right. Previously the buses reversed from where the passengers are standing back around the end of the terminus to park behind the cable cars in Figure 26 and then pick up passengers, a process considered somewhat dangerous.

BACKWARDS AND FORWARDS

Looking backwards, using rimu timber in the ground for the tunnels was a mistake and today the concrete tunnels would have been reinforced. Looking forwards, it was good that lessons being learnt from the Mornington line were applied to the last of the cable car lines: Stuart St – Kaikorai.

Looking around ask how many other transport systems have 3 braking systems? And of course braking directly onto the ground, as opposed to only through wheels, is good especially with ice or snow on steep slopes. For even more braking, could it be worthwhile revisiting the Roslyn Dolphin brake (steel friction wedge in the tunnel slot) especially using the later Kaikorai slot design that eliminated timber? And for slipper brakes are there modern materials with coefficients of friction greater than timber?

The replacement of the turntable for switching cars onto the down line by clever track design plus the dip in the track allowing automatic pick up of the cable and elimination of cable hooking are all good examples of continual past improvements and a credit to New Zealand Engineering.

Operationally, the 1889-1890 running of 2 trailers behind 1 grip car was an eye-opener. Although stopped by the PWD, the system was proven!!

Looking forwards to cable car reinstatement, any new rolling stock to supplement the restored heritage cars and trailer should be designed to allow this modus operandi, and of course the haulage capacity designed to suit. Two trailers would be an excellent and flexible way of coping with medium and peak demands.

The very forward idea of reinstating the Mornington system though first needs street earthworks to increase the radius of the convex and concave curves allowing more pulleys at each curve so getting the cable deflection per pulley down to modern criteria. Pulley anchorage in the tunnel will need careful design. And should the Roslyn line's drum pulleys be revisited in lieu of Mornington's curve pulleys? With the advantage of hindsight and forward technology, reduced cable wear and reduced problems will surely win out.

And much as a heritage operation would be excellent, radio equipped grip men and conductors will be essential when it is necessary to stop the cable in an emergency, or communicate with any engine room operator.

The cable cars provided good fast travel up the very steep suburban hills with passenger loading and alighting rates being far faster than buses, and transporting superb numbers of people.

✕ The author remembers standing at the exchange terminus when trolley buses supplanted the cable cars. He still has not got over how long they took to load. It was unbelievable.

✕ The author vaguely remembers that when trolley buses took over the Stuart St – Kaikorai route, their motors had over heated when they got back to the turnaround place (Octagon or Railway Station?) and had to be routed onto a flat run before returning to the Kaikorai route. Too steep for trolley buses?

✕ Environmentally, diesel buses, no.

Let the years have the final say.

✕ The much-vaunted trolley buses lasted merely 31 years. [ODT 1 Apr 1982 p1]

✓ The Mornington cable cars and trailers, going so well at closure, and electrically driven, had operated for 74 years.

The sad day

The author's ticket from his last cable car trip on the morning of the last day. It should have been the afternoon but the Otago Boys' High School fund raising gala was on. To have wagged would have been to be lined up outside the rector's office on Monday morning. By reputation, an event more painful than missing the last run.

PART 3: CONCLUDING SECTIONS

CONCLUDING COMMENTS

The construction of the Roslyn and then the Mornington cable tramways in Dunedin at beginning of the 1880s was indeed a bold venture. In 1881 when the Roslyn line opened, only a few of the many cable tramways that San Francisco eventually hosted were in operation and the technology was very much in its infancy. Whilst the hilly nature of Dunedin made cable tramways an attractive proposition, the commitment at the time was a brave venture that, with the skill and tenacity of locally born engineer, George Duncan, succeeded, and in turn made contributions to the technology, most notably through Duncan's devising of the 'pull curve' where steeply graded tracks have changes in direction.

That the cable tramways in Dunedin survived through until the 1950s, albeit later under City ownership, is a testament to the vision and bold commitment of George Duncan and those who formed the original private Tramway Companies.

Reminders of the early cable tram ventures in Dunedin are now limited to a small number of cable cars that have been restored and on public display. Of recent times, various proposals have been advanced to reconstruct the Mornington cable tram line as a tourist attraction, which it undoubtably would be, with San Francisco currently the only city in the world to have reinstated several of its firmer cable tram lines.

After the Mornington line opened, George Duncan was ‘head hunted’ by Francis Clapp, who had formed the Melbourne Tramway & Omnibus Company, and moved to Melbourne as engineer for that city’s cable tram network which by its completion in 1891 was second only to San Francisco with some 70 km of track that was operated by the MT&OCo.

ACKNOWLEDGEMENTS

Christian Scartezzini of Leitner who stopped work and gave the Mornington author an hour of his time when he arrived near unannounced.

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Noel Leeming. Nelson. Tech Solutions staff.

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Those with whom we had personal communications by e-mail and/or phone.

Those whose names appear in image citations.

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ABBREVIATIONS

DCC Dunedin City Council.
dwg Drawing.
ES Evening Star. Daily newspaper, Dunedin. Now closed.

ESD Evening Star.

Hocken Collections: Hocken Collections - Uare Taoka o Hākena, University of Otago. Dunedin.

MBC Mornington Borough Council.

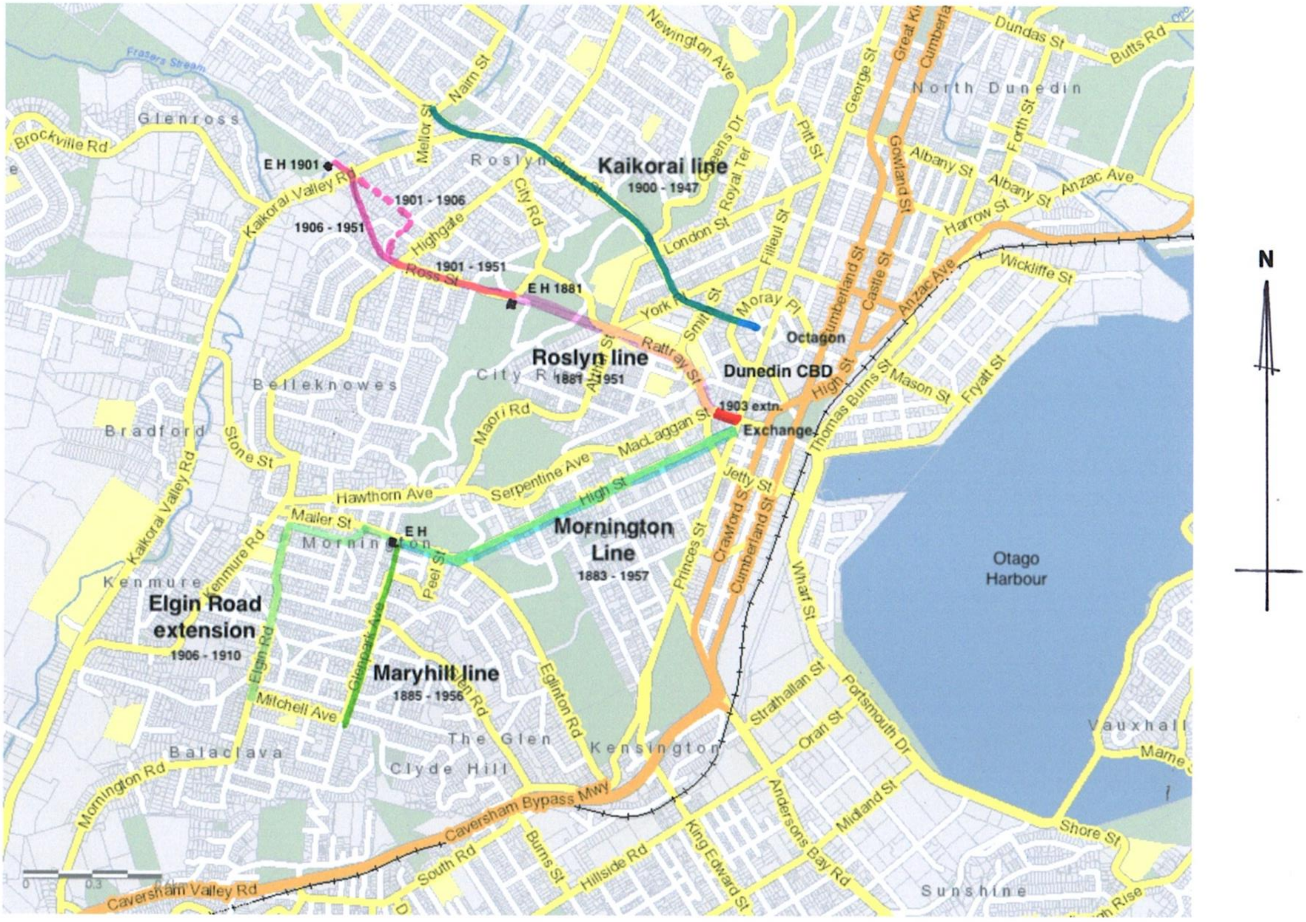
MMT Mornington Municipal Tramways.

MTC Mornington Tramway Company.

n.d. No date.

ODT Otago Daily Times. Daily newspaper. Dunedin.

PWD Public Works Department. (Later: Ministry of Works. Later still: Ministry of Works and Development.)



Appendix A **MAP SHOWING ROUTES OF CABLE TRAM LINES** **E H = Engine house**

REFURBISHING ENGINEERING HERITAGE FOR PRESENT DAY USE

engineering new zealand HERITAGE

REFURBISHING ENGINEERING HERITAGE FOR PRESENT DAY USE: WRITER BIOS

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Robert is a semi-retired career railway man. While always based in Dunedin, he has had extensive involvement with track throughout the South Island. In the last 20 years Robert has assisted with the development of an Infrastructure asset management system plus associated track GIS data, recovery work after the Kaikoura earthquakes, and mentoring young engineers. He is now focusing on various aspects of rail heritage.

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Sam is a section 45 approved archaeologist with 8 years' experience in professional practice. Career contributions have included working on the Kaikoura and Christchurch Earthquakes recovery and rebuild, and other large-scale infrastructure projects around the South Island. Sam was the lead consultant archaeologist with WSP on the Ross Creek Project.

CO-AUTHOR SCOTT KVICK

Scott has been closely involved with the Ross Creek facility since starting his engineering geology career with WSP in 2014. The opportunity to witness 150-year-old features being exposed during refurbishment earthworks operations has been a feature of his contributions to dam safety management, geotechnical investigations, construction supervision during the refurbishment, and the staged recommissioning of the reservoir.

A SERIES OF MOST FORTUNATE EVENTS: BRINGING NEW LIFE TO OLD TECHNOLOGY AT MANDEVILLE, SOUTHLAND, NEW ZEALAND

Robert Storm, NZCE(Civil)

Summary: Some 20 years ago a new rail heritage endeavour was established in Southland to look after K92, a restored Rogers Locomotive from 1878. The vision was to establish a working museum, based around railway operations between 1878 and 1920. So, the next 15 years were spent collecting items and incorporating them into an ever-evolving development plan.

A turntable was located on a farm nearby, having narrowly avoided the scrap merchant. It was remarkable to trace its history back to one of the 8 turntables imported with the Loco.

A set of bowstring roof trusses was acquired as part of a demolition project, little knowing that they too had a significant history in being able to be traced back to one of the original buildings erected for the Hillside Railway Workshops in 1876.

This paper documents the journey to understand the heritage significance of these items which form key parts of the Trust's expanding facilities at Mandeville.

Rogers Locomotive, Turntable, Bowstring truss, Hillside Workshops, K92

INTRODUCTION

Let me start with a quick reflection on the title of this paper, and thank you to Daniel Handler (aka Lemony Snicket), author of a children's book series for some late inspiration there.

There are a number of things that have quite remarkably eventuated over the years that I can truly say have put us in a fortunate position. By 'us', I could mean the Waimea Plains Railway Trust, but could just as easily extend that to all who will visit there in the years ahead, or New Zealand society as a whole as it seeks to preserve items from its relatively short history. While the Trust has managed to collect some unique treasures, and each of these could tell their own story, collectively they make a much more significant contribution to the record of early railway development in our country. When you consider the word 'fortunate', it comes from the word 'fortune' which has all sorts of connotations about value and wealth. However, at the time certain decisions were made about each of the items discussed here, they certainly didn't seem to have attached a lot of value to them. Yet, the way they have all ended up at an unexpected site in Southland is truly remarkable and adds immensely to their heritage value.

I have decided that the best way to present this material is in the form of a history lesson. While I am no history teacher, and neither did I have much of a taste for history when at school, I have found that history seem to grow on you as you leave your own mark on society and you appreciate more what others before you have achieved. Without understanding our history, it is very difficult to get your head around why certain decisions were made, and from our perspective of hindsight, it is all too easy to be critical of many of those that were made.

1870 – 1882

So,…try and imagine what life was like here in Dunedin 150 years ago.

The citizens were living in a town that had only existed a mere 25 years, but they had already made quite an impact on what were largely untouched surroundings when they arrived. The town had been 'laid out', defining the major streets; much reclamation had been carried out; a 122m (400ft) long jetty built, and substantial stone buildings were being erected.

But this was a time when travel was still very arduous, there was a huge reliance on coastal shipping because roads between main centres were little more than what we would today call a 4-wheel drive track, and as soon as you went off the main roads you were restricted to horse-back only. For some years already, dramatic changes had been taking place 'at Home', the era of Railways had started in Britain some years before most of our immigrants left their homeland, so those that came to Dunedin (and to most other centres no doubt), were all discussing ways in which railways could make a difference to their new home town.

While Otago was a little slow at adopting the modern wonder of rail transport, the Dunedin & Port Chalmers Railway, opened in December 1872 [19] holds the distinction of being the first public railway in New Zealand to operate on the recently set national track gauge of 3 foot 6 inches (1067mm). In world terms, this was narrow gauge with some strong opposition to its adoption. Christchurch had adopted Broad, or Irish gauge (1600mm) [35], and Invercargill Standard gauge (1435mm) [45] as their preference and both went through painful periods of changing gauges.

But just a matter of months after work started on the Port Chalmers railway, tenders were being called for the first section of a line south to the Clutha River [23] and only 8 years later, you could travel from

Christchurch to Invercargill by train. Some of the key decisions that both leading up to that point, and some in the years that followed that forms the heart of what I will talk to you about today.

Our specific interest focusses on two localities, Dunedin and Mandeville, Southland. Dunedin is where it all started and where three significant items played a key role, and Mandeville is where those three items have ended up, so let us roll back the years and see how that all came to pass.

First let us take a quick look at the growth of railways in the South Island, there were several main drivers.

- There was early recognition that reliance on coastal shipping was fraught with problems, so a railway linking the main centres was very desirable.
- Given that roads were poor in most areas, having a rail service to the main agricultural centres of the provinces would significantly reduce the cost of exports.
- Queenstown was already a tourist destination by 1870, so a rail link to Lake Wakatipu was most desirable.
- With Gold having been discovered in Otago in the 1860's, there was an urgent need to improve transport routes into Central Otago.
- Towns relied on coal as its primary source of energy, so rail access to the various coal mines was paramount.

Each of these drivers led to decisions about the route for the Mainline as well as the sequence of construction of the various branch lines, and into that mix we have to include Politics. While every town wanted a slice of the 'Railway-pie', the politicians had to ration the available funds, often turning the taps right off as the country seemed to plunge from one economic depression into another.

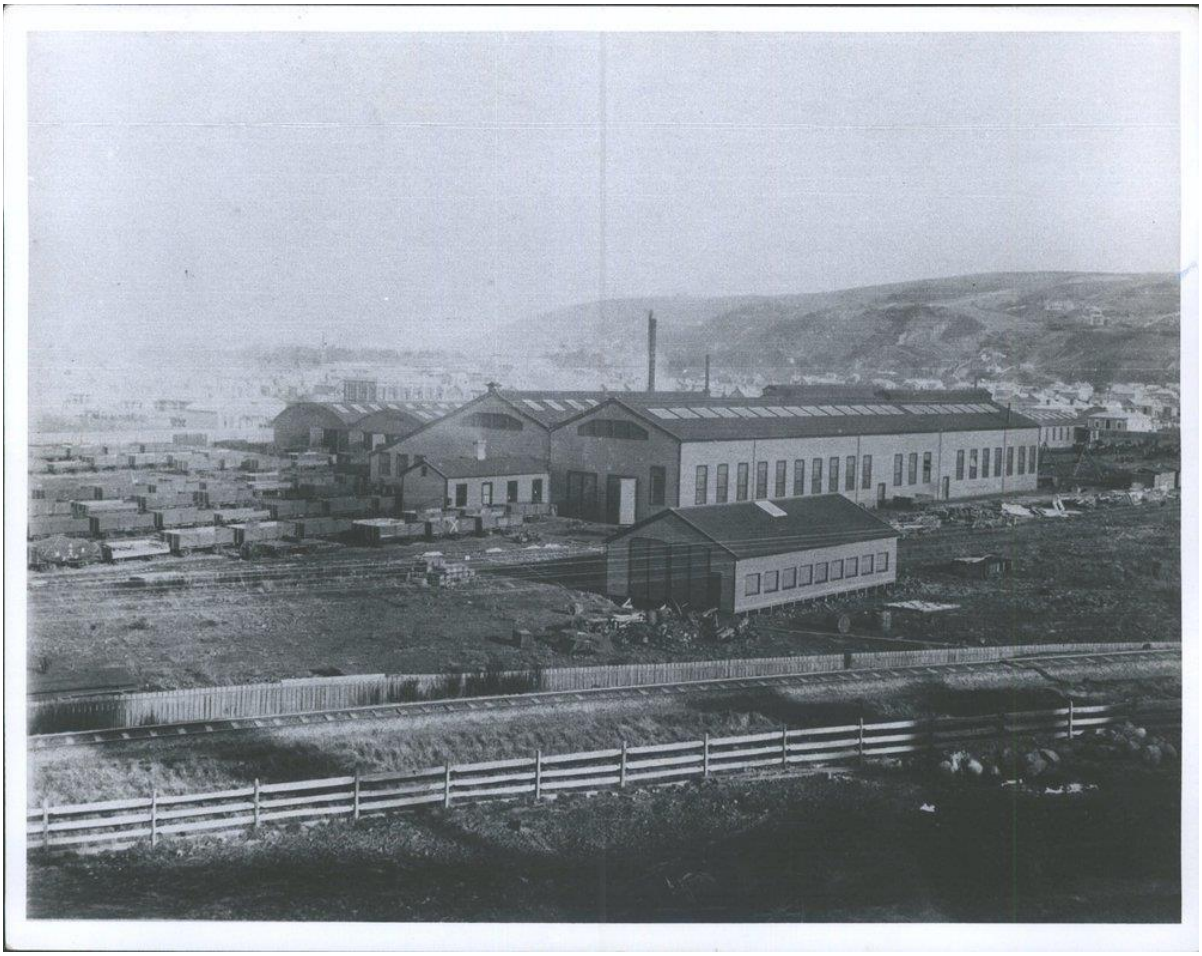
Once railways became part of the economic life of the various centres, an insatiable demand for railway wagons developed, but they could be neither built nor maintained fast enough. Nation-wide, repair facilities were woefully inadequate and in Dunedin there was much indecision about whether new workshops should be built at Port Chalmers or in Dunedin City [7]. Ultimately a site at Hillside was acquired [30] (only a part of the current site) and led to the establishment of the first formal Railway Workshops in New Zealand. Others soon followed at Addington, Petone, East Town and Newmarket.

The first large workshop building was constructed at Hillside in 1875 [24], and that still exists today (but probably not for much longer due to a site redevelopment). This was followed by a Carriage Painting shop [25] and a Carriage Repair shop both probably completed in 1877 [26]. Then, following much protest about Otago rolling stock being sent to Addington for repairs due to the lack of facilities at Hillside, further expansion took place in 1881 which included a late decision to increase the Carriage Painting shop to triple its original size rather than just doubling it [32]. Regular expansion continued through into the early 20th century that saw the addition of a boiler house, iron foundry , blacksmiths shop, store and many other smaller buildings.

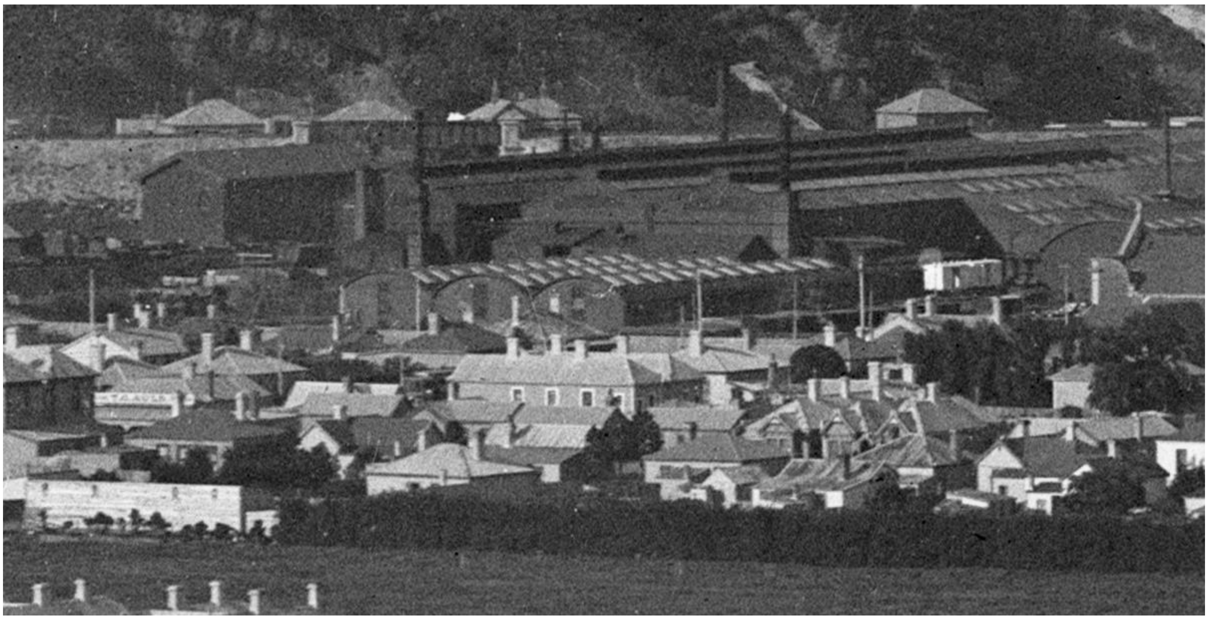
Of these early Hillside buildings, the Carriage Painting Shop contained our first item of interest, its wrought iron bowstring roof trusses, which add a unique feature to what would otherwise be a very plain industrial building. As we will see shortly, this building survived about 125 years of use on two sites and the trusses have now been reused at the Mandeville rail heritage site.

The bowstring truss design was invented by Squire Whipple and awarded US patent No 2064 on April 2nd 1841 [13] It was the first-ever all metal truss design, using a combination of cast and wrought iron and at the time used for bridges over shipping canals. Nowadays, the design is more usually restricted to large span roof trusses.

[Figure 1] Vischers Ferry Bridge across the enlarged Erie Canal (relocated from 2 earlier sites. [13]



[Figure 2] Hillside Workshops circa 1883 viewed from the north west, with the original workshop building in the centre, the Carriage Repair Shop behind on the left, and the Carriage Painting Shop behind in the distant right. The mainline is in the foreground, still at its original low level.[43]



[Figure 3] A view of Hillside Workshops from the south east c. 1910, with the Carriage Painting Shop recognisable by its 3 curved roof sections. The original Machine Shop is immediately behind it and you can just see the curved roof of one part of the larger Carriage Repair shop to the right. The mainline is in the background, now on a high embankment. This is a small section enlarged out of the photo entitled "The Flat, Dunedin" made available by Te Papa [18]

To discover the background to our other two items of interest, we need to return to the year 1875 where we find that Railways are still very much viewed as Provincial resources by the locals. At that point in time, each Province had specific rail projects they were promoting to advance their economic prosperity. But in the background, the Government was already quietly envisaging a national network. As sections of Provincial lines started to be linked, it soon became apparent that travel options were about to change, Otago was about to be linked with Canterbury which occurred in Sept 1878 [12], and the link to Southland soon followed in Jan 1879 [10, 37]. In many ways the South Island was fortunate to get a continuous line of railway from Amberley in North Canterbury, down through Christchurch, Dunedin and Invercargill, and back up to Kingston by early 1879. A total distance of 780km of track This linked all the important communities along the east coast and up into the tourist area of Lake Wakatipu, and all constructed in less than 10 years. New Zealanders were now in the era of long-distance train travel.

Long distance travel required locomotives that could carry significant quantities of fuel. This in turn led to the development of the Tender Engine, minimising the number of times water and coal supplies would need to be replenished. Tender engines were however required to operate mainline trains in a forward direction to ensure the driver could see the track ahead, which led to the development of locomotive turntables. These were placed at strategic stations along a route so engines could be turned ready to take a train in the opposite direction when required.

Back in 1875 already, the Locomotive Engineer anticipated these needs, and realising that none of the current locomotives he had available were suitable for that sort of task, set out to find what was available. It is still unclear how the final decision was reached, but I am sure the 1876 Centennial Exhibition in Philadelphia played a key part. New Zealand both exhibited there, and had official representatives attend where no doubt many seeds were sown by American companies and their representatives, keen to break into the British dominated markets. So, contrary to everyone's expectations, fast passenger locomotives were ordered from America rather than from the 'Home country', which had been the source of all earlier Railway requirements. The sudden purchase of locomotives from the USA was therefore quite a departure.

Along with an order for, first 2 locomotives, soon followed by an additional 6, from the Rogers Locomotive Works in Patterson, New Jersey, an order was also placed for 8 turntables from William Sellers & Co. of Philadelphia, Pennsylvania, reputedly the best turntables in the world at the time. [4,40]

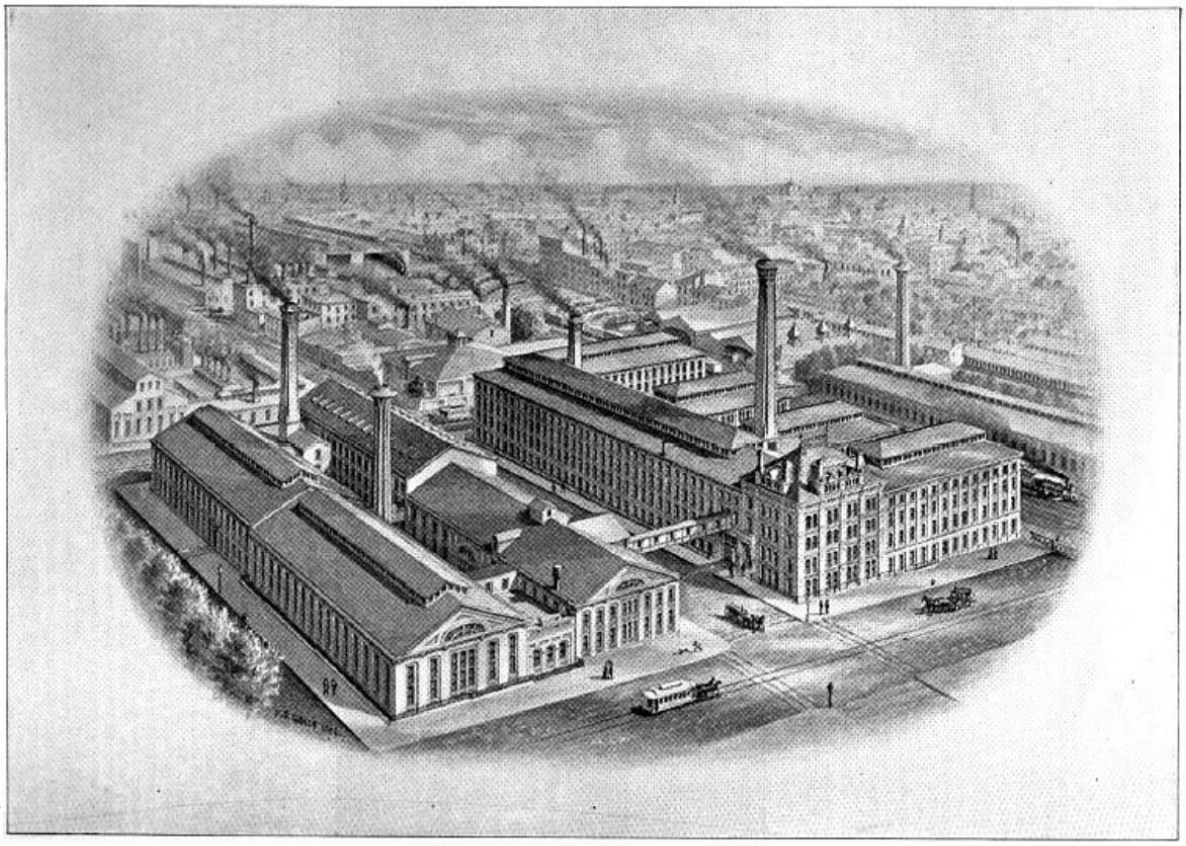
Eight was not a number plucked out of the air, neither did it mean there was one turntable for each locomotive, no, some careful analysis of requirements would have been made. These would have been based on proposed train timetables and pulling ability on various grades, to ensure sufficient engines were available for the work required, as well as allowing for breakdowns and maintenance.

The ordered equipment duly arrived in Lyttelton, the first two locomotives (K87 and 88) in February 1878 [16, 17] on the ship *August Frederick* [31] with four of the cast iron turntables and many of the machines for the Workshops already off-loaded in Dunedin [41]. Six further locomotives (K92 – 97) along with the other four turntables arrived in October 1878 on the ship *Southminster* [8, 36]. One of the locomotives in that second batch was K92 and one of the turntables quite likely No 669, these are our other two items of interest and we will explore the history of both of these in some greater detail.

The first train into Dunedin from Christchurch arrived on the evening of September 6th 1878 [12], quite a few months before the Sellers turntable was operational in Dunedin [33], and yet the loco had to be turned for the trip north the next day. The only option was to use the much smaller turntable provided for the Dunedin & Port Chalmers Railway, but at 6.1m (21 feet) diameter, that meant splitting the tender and engine, and turning each separately, then coupling them together again [42]. This added considerably to the drivers work-load so completion of the 15.2m (50 foot) turntable adjacent to Rattray St in May 1879 will have been very much appreciated.

The K class locomotives were initially allocated to Christchurch, Timaru and Dunedin working the Express trains but as soon as the Main South Line was completed, they were operating right through to Invercargill and up to Kingston.

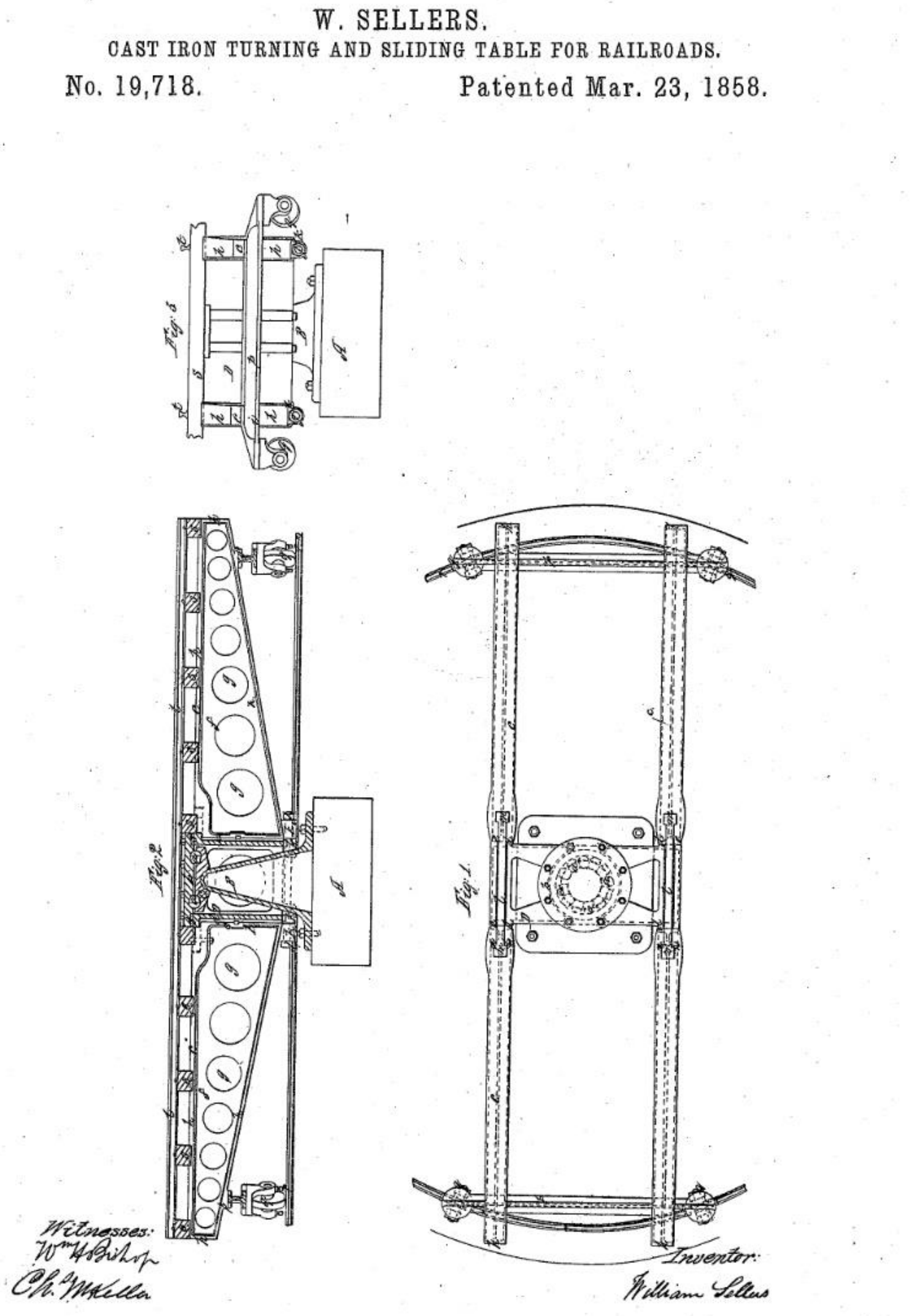
So, let's take a closer look at the turntables. William Sellers was a highly respected mechanical engineer and instrumental in standardising many aspects of engineering in the USA, just like Sir Joseph Whitworth was in England. He established a large engineering works in Philadelphia, specialising in supporting the rail industry with machinery of all types.



WILLIAM SELLERS & COMPANY'S (INCORPORATED) WORKS

[Figure 4] William Sellers & Co's works in Philadephia covered 2 city blocks [44]

His other well-known railway apparatus is the Sellers' steam injector, widely used in New Zealand, and he also developed a much-improved design of machine shafting. He was granted a patent for his turntable design in 1858 and sold them throughout North and South America, Europe and Australasia. Each had a serial number which in the case of the New Zealand tables was cast into the bearing cap. New Zealand Railways did not keep any records of these numbers, and William Sellers & Co's own records seem to have been lost among the various mergers since 1947. All I have been able to conclude is that the table installed in Dunedin in 1879 was number 669 and from other research, I have carried out, can be confident that these numbers were issued sequentially during nearly 50 years of manufacture with more than 1300 made in total.

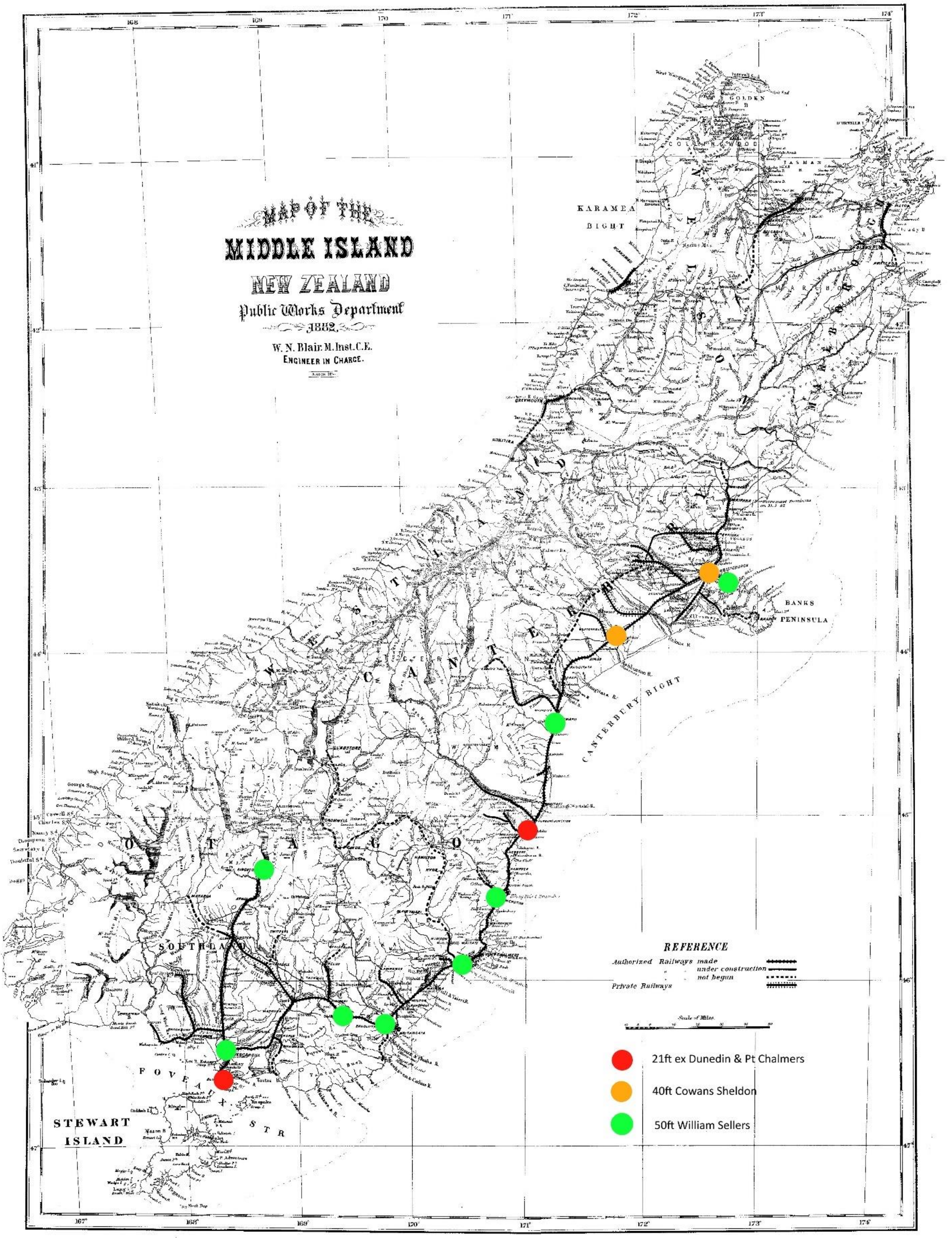


[Figure 5] William Sellers Cast Iron Turning Mechanism Patent drawing from 1858 [39].

We find that each of the turntables to arrive in New Zealand had pre-allocated sites for installation. Eight locations had been identified to meet the needs of passenger trains for the immediate future as shown in the following list [41].

- Lyttelton 1879 – Northern end of the Express Passenger Service
- Palmerston 1879 – Northern end of the Hilly section requiring an extra loco
- Dunedin 1879 – One day's travel from Christchurch
- Clinton 1879 – Halfway Dunedin Invercargill
- Timaru 1880 – Roughly halfway Lyttelton – Dunedin – a secondary Loco Depot
- Balclutha 1880 – the only significant Loco Depot between Dunedin and Invercargill at the time
- Invercargill 1881 – Southern end of the express Passenger service
- Kingston 1882 – End of the Kingston Branch

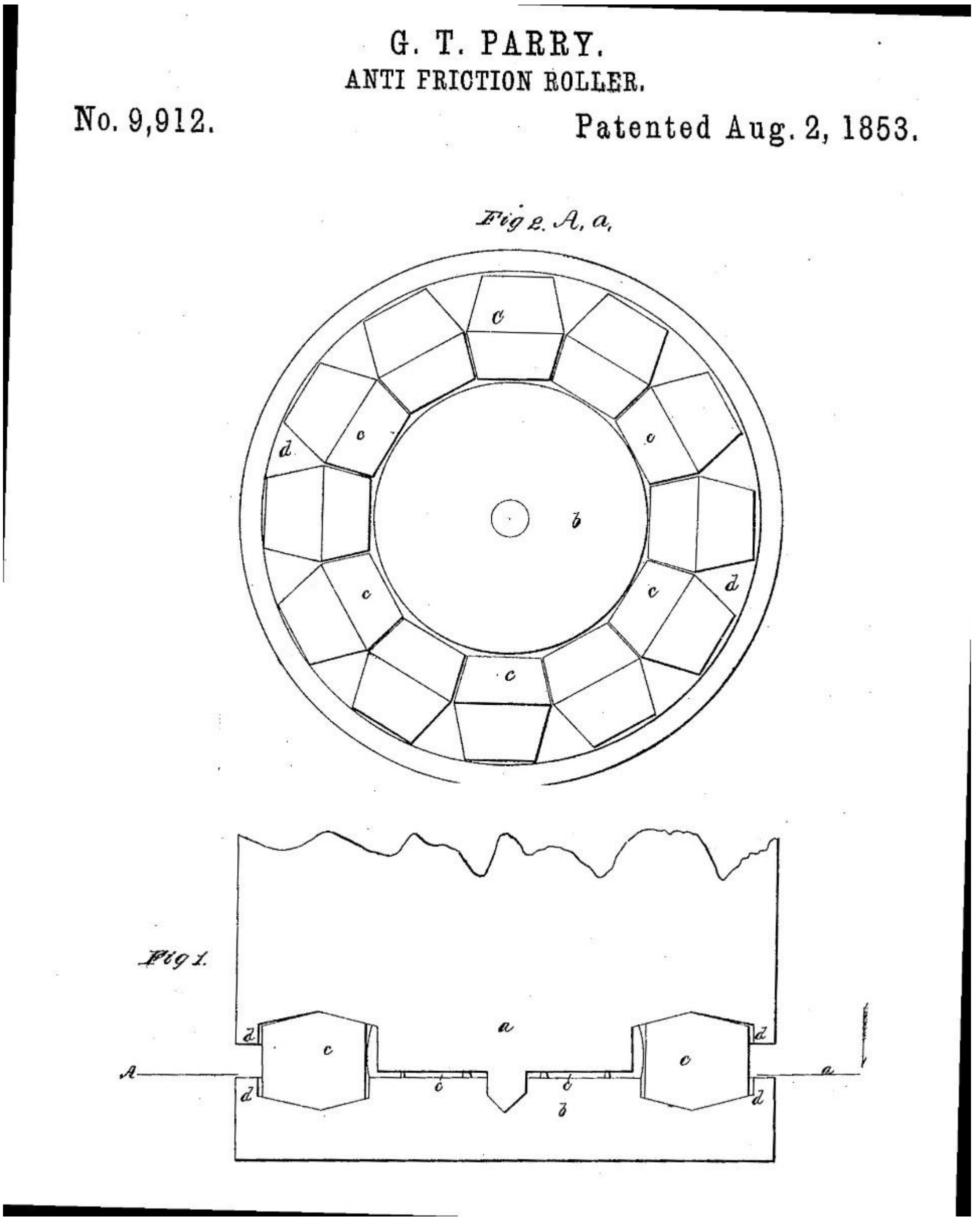
A fact to keep in mind is that Christchurch and Ashburton both had 40ft (12.2m) turntables manufactured by Cowans Sheldon, Carlisle, England, and imported for the first J class freight locomotives. These tables were just big enough to accommodate a K loco. Oamaru and Bluff both had 21ft (6.4m) tables for a short while, assumed to be ex the Dunedin & Port Chalmers Railway, and able to turn the loco and tender separately if required.



[Figure 6] Map showing railway construction progress in 1882 as presented in the Public Works Statement for that year [38]. Note: turntable data has been added by the author.

As you can see, these locations are strategically spread throughout the network of the time, enabling tender engines to operate from several ‘home’ bases. In this way the long route could be divided into sections if needed, each operated by different locos. This covered things like breakdowns, and the need for a second Loco (a banker) on the steep Palmerston – Dunedin section. When the Christchurch to Dunedin Route was first completed in 1878 [2], through passenger trains were able to complete the journey in 11 hours. Less than a year later you could travel on to Invercargill the following day, taking a further 6 and a half hours [21]. These trains operated each way, each day, using engines based at Invercargill, Dunedin, Timaru and Christchurch.

A key feature of the Sellers’ turntable design was the use of another recently patented item, the Parry anti-friction bearing, which has evolved in to what we know now as the tapered roller bearing. These bearings were able to support the largest locomotives of their day (around 50t) and still enable the engine to be turned by one person.



[Figure 7] The patent drawing for the Parry anti-friction roller bearing from 1853 [34].

The other important design feature of the turntables was that they could be easily dismantled for relocation at a new site, a feature that was very attractive to railways in times of expanding networks. A detailed analysis of New Zealand's turntables shows that most tables were relocated at least once over their life-span and some of them quite a number of times [41].

[Figure 8] Dismantling a turntable. A comparatively modern photo, thought to have been taken at Tuatapere in 1977 with the turntable destined for Clyde. While this is a larger 55ft table manufactured in New Zealand, it retained the modular construction exactly as designed by William Sellers. From the author's own collection.

Construction of the railway routes these turntables were purchased for was well advanced by the time the order for them was placed, but in Dunedin the actual installation was delayed pending completion of the reclamation for the new station (Dunedin's third Station [5, 6]), sited where the Chinese Garden and Settlers Museum are now [30].

By this time though, plans for railway expansion in Dunedin were well in hand. Tenders had been called for a huge new reclamation over 1km in length to provide space for the rapidly expanding railway [9, 11, 27]. The project included extensive shunting yards with goods sheds and a dedicated locomotive depot at the south end. Turntable 669 consequently became the first 50ft (15.2m) turntable in New Zealand to be relocated, making use of the fact that they were designed specifically with that need in mind.

1883 – 1930

New Zealand Railways continued to expand over the following years so there was soon a need for many more turntables. Rather than buy more from W. Sellers & Co, it was decided to manufacture the tables in New Zealand, and with the Locomotive division headquartered in Christchurch, Addington Workshops became the base for their construction. At the time, Addington had no foundry so, along with other casting requirements, that work was done at Anderson's Foundry. From extensive research of available records, I have concluded that 19 were manufactured as copies of the Sellers' tables between 1884 and 1892 [41].

However, as new locomotives got heavier, it became apparent that they needed a stronger turntable design so again Andersons Foundry was used to cast 19 heavier 50ft (15.2m) tables over a 7-year period [36]. By this time, there was so much work for turntable 669 that Dunedin got a second turntable. This was one of these stronger 50ft (15.2m) designs and was placed at the south end of the engine sheds while table 669 remained at the north end.

By 1900, Addington Workshops had its own iron foundry capable of doing all the railway work but new loco designs meant longer turntables were required so over the next 25 years, about 32No 55ft (16.7m) long tables were cast and machined at Addington [22] and later Hillside. In all, it appears around 70 cast iron turntables were manufactured in New Zealand over a period of some 45 years, with examples of each still existing [41].

A consequence of increased demand for rail travel, particularly from suburban passengers meant that there was soon insufficient capacity on a single track to move the number of trains that were needed between Dunedin and Mosgiel. This triggered another major expansion beginning in 1907 which saw the whole route from Ravensbourne to Mosgiel converted to double tracks over the next 7 years [28]. This allowed trains to travel in either direction at the same time, more than doubling capacity. It also involved significant improvements to curves, grades and tunnels, and placed the railway on an embankment all the way through the southern part of the city. This had consequences for turntable 669 as well, as the locomotive depot, now some 25 years old was now far too small for the number of engines based in Dunedin. With the new double track alignment cutting through the old loco depot site, turntable 669 was retired from use having served 32 years of continual service in one of the country’s busiest yards. With new 55ft (16.8m) tables now available, there didn’t seem to be a need for a light 50ft (15.2m) table anymore, never the less, table 669 was tucked away in a corner and all but forgotten about. That was until a call went out 2 years later urgently needing a turntable for the Tapanui Branch in northern Southland. So here we have another fortunate event, because turntable 669 would ordinarily have been scrapped (at worst), or just kept as spare parts for the few Sellers tables that were still in use in Southland. But no, it was to spend its retirement years turning one or two engines a day a few days a week for the years to come.

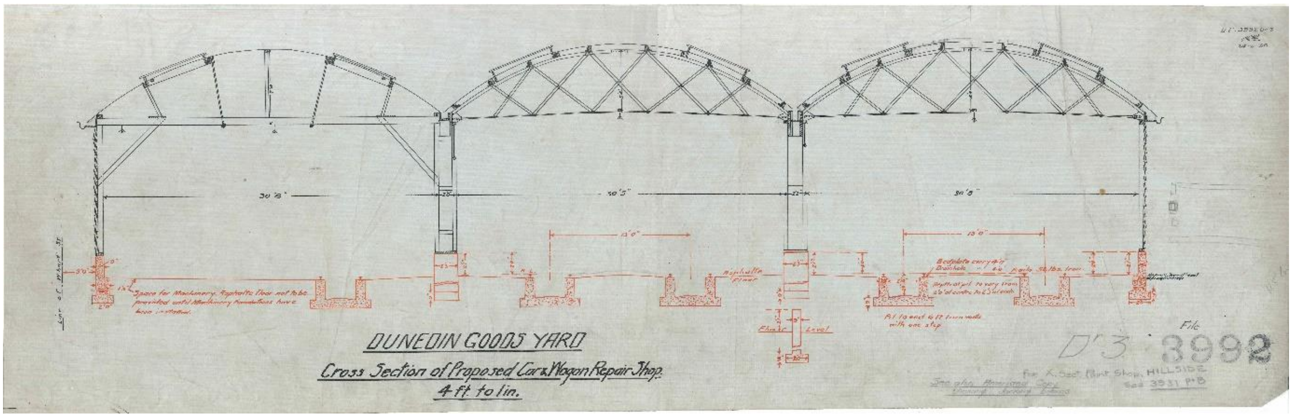
But we must keep in touch with our other treasures as well, so back to 1900. With demand for travel growing rapidly and trains getting longer, the little K locos could no longer compete with newer and larger locomotives for the main line work. Within a few years they were relegated to less demanding tasks without the steep grades and big trains. The Waimea Plains Railway had been completed in 1880 as a private venture by Dunedin business interests [20]. On 1 April 1886 it was taken over by the Government [20] and it wasn’t long before one of the tasks the K locos were given was to pull the Gore to Kingston train and here it quickly gained popularity and received the nickname “The Kingston Flyer”. This was due to the spritely performance of the K class loco’s on the relatively easy terrain in Southland. But like all new technology, new models continued to appeared and even with new boilers and fireboxes, these locomotives had outlived their useful life by the early 1920’s and were progressively withdrawn from service. Most were scrapped (the usual fate of retired locos), but our third most fortunate event was that 5 of the 8 K’s were deemed to be worth a little more than their scrap metal price if they were buried in a river bank to protect the railway line from scour during the frequent floods that swept down the Oreti river. So nearly 100 years ago, K92 was laid to rest in the banks of the Oreti River at Mararoa, (just upstream from Lumsden) along with a number of other locos, and K88, 94, 95 and 97 were placed at Branxholme near the Invercargill water intake [1].

The early 1920's saw big things begin to happen on another front. There was to be a complete modernisation of all the Railway Workshops and Hillside was to get seven large new buildings. Many of the original buildings were in the way of the new ones including the Carriage Painting Shop, and the Carriage Repair Shop. To avoid too many difficulties during the construction phase and to provide an ongoing facility in the yard, the paint shop was relocated there to become the Car and Wagon shop (colloquially called the Gully) where light repairs could be carried out, avoiding the need to go to Hillside to have matters attended to [29].

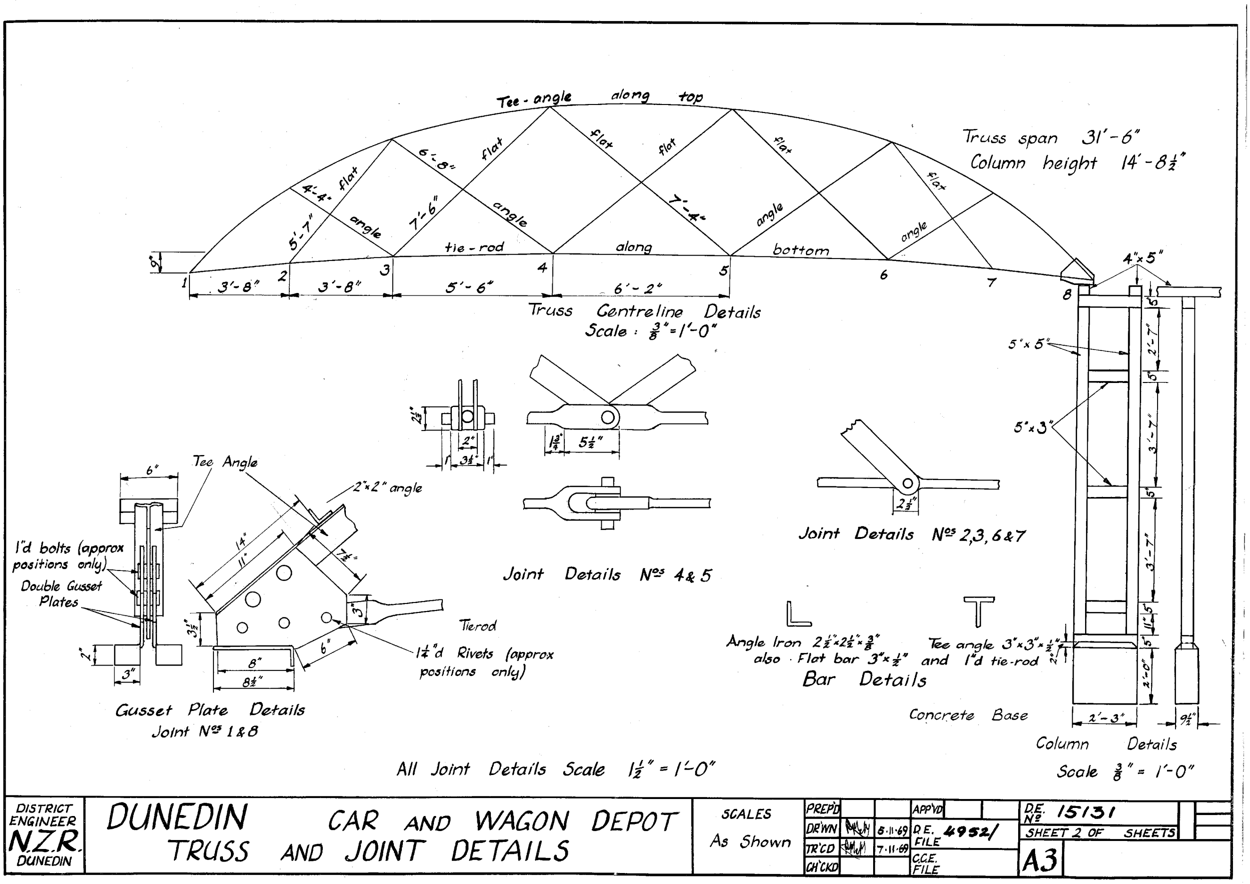
1930 – 1975

The next 45 years passed by rather uneventfully for each of our three items, K92's grave remained undisturbed by floods at Mararoa, Turntable 669 kept doing her job at Heriot but was occasionally taxed beyond her limit by heavy engines, and the trusses continued to support the roof of the Gully building, providing a dry workplace for the staff there.

My first formal encounter with the Gully building was the year I starting work at NZ Railways, for in November 1969 I was asked to help-out measuring up the roof trusses as they couldn't find any drawings for them. It is a task I still vividly recall as I soon found out that the reason I was asked to assist was, my colleague was scared of heights, meaning I had to climb on all sorts of makeshift supports to get to the joints so accurate measurements could be taken. One thing we didn't pick-up on at the time though was that each of the 3 bays in the building was a slightly different dimension, something that would become of significance later on. Many years later I found the drawing that was prepared for the building relocation from Hillside to Dunedin Yard, clearly showing each bay was slightly different.



[Figure 9] NZR Drawing Dun3992 dated 24/02/1926 showing a cross-section through the building as it was to be built in Dunedin Yard. I have not been able to locate the drawing that shows the cross-section of when it was still a carriage Painting shop at Hillside.



[Figure 10] NZR drawing Dun15133 dated 1/11/1969 showing the Car and Wagon building trusses and joint details as measured.

1975 – 2000

October 1978 was the trigger date for changes to the quiet life for our three friends. While New Zealand is quite familiar with flood events, the storm that unleashed itself around Tapanui that year was sadly the death knell for the little branch line [3, 15]. There was so much damage to the railway that reinstating it could not be justified given there was only one train running 1 - 2 days a week, and what happens to branch lines when they are no longer required? Yes, they are sold for scrap. But for turntable 669, there was another fortunate event in that it was separately advertised for removal rather than being part of the main track recovery contract. There were two tenders received, one from a farmer, but a better price from a scrap merchant, but again most fortunately, the scrap merchant's tender had arrived one day after closing and deemed invalid, so turntable 669 was sold to farmer Brook who wanted to use it as a bridge on his farm. We were later told that he towed it 'home' in one piece behind his tractor and, being made of cast iron, it was again most fortunate that nothing broke. Having got it to the farm in one piece, it was perhaps a big disappointment to find that the design of a turntable relies on it being supported at its centre, not its ends, so it could not easily be adapted for use as a bridge, so most fortunately, all its parts were left in the corner of a paddock, a problem too difficult to solve.

Meanwhile, the Car and Wagon Depot was having some drama of its own, a fire in the early 1980's was fortunately able to be contained with less than 20% of the building being seriously affected. The building continued as a light repair shop in a slightly smaller format till about 1991 when major locomotive work was concentrated into Christchurch, freeing up a lot of space in Dunedin's much more modern Loco Depot. This brought to an end 115 years of use as a Railway maintenance facility. But wait, Dunedin had another railway in the form of The Otago Excursion Train Trust. They were keen to lease the building and adjoining tracks to maintain their growing fleet of carriages, so in the meantime its future was secure.

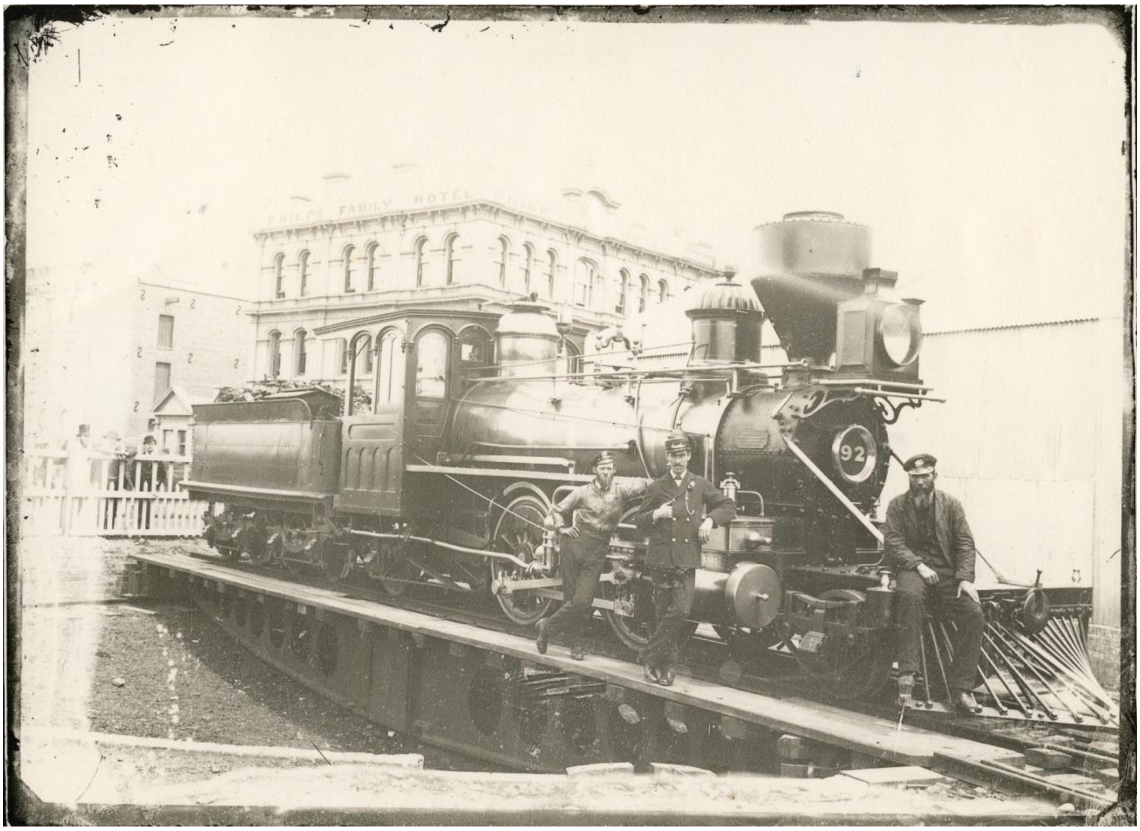
With locomotive K88 having been recovered from Branxholme in 1974, and restoration completed in 1982 by the Plains Vintage Railway at Ashburton, moves were made by the Fiordland Vintage Machinery Club to exhume what remained of K92 at Mararoa. This finally eventuated in 1985 and so the long process of its restoration started.

[Figure 11] Locomotive K92 in the process of being recovered from the Oreti River bank at Mararoa in 1985. Photo from the Waimea Plains Railway Trust archive.

Due to unforeseen circumstances, the club could not carry the restoration through to completion and eventually ownership was transferred to the Waimea Plains Railway Trust to complete the task, finally achieved in 2001.

[Figure 12] Locomotive K92 on the occasion of her 130th birthday celebration while at Kingston. She is now operating at Mandeville about once a month from October – April. Photo by the author.

This Trust had been established for the express purpose of keeping the locomotive in the area that made her famous, and with a dream of establishing an operational steam heritage railway precinct at Mandeville. As with every new venture, a huge task lay ahead of it in securing the many other assets required to realise their dream. Part of that search focussed on acquiring a turntable, and surprisingly one was soon found on a farm not far away. What was more surprising though was the discovery that this was Sellers turntable 669, which had been imported from America in 1878 along with the loco K92. Turntable 669 has now been restored and placed on a new foundation ready to start a new lease of life, turning one of the locomotives it was originally purchased for. While researching the Sellers' turntables I made another surprising discovery in the form of a photograph among Jim Dangerfield's material at the Hocken Library. It shows locomotive K92 on turntable 669 at Dunedin in about 1892. Before long we hope to be able to re-enact this scene to truly commemorate the bringing together of these two pieces of railway engineering history.



[Figure 13] Locomotive K92 on Sellers turntable 669 at Dunedin c.1892. Hocken File S14-560.

[Figure 14] Sellers turntable No.669 reinstalled at Mandeville but awaiting resources to complete the pit walls and track. Photo by the author.

Finally we must move back to Dunedin where the Gully Building was still in use as the carriage maintenance workshop for the Otago Excursion Train Trust. It was also where K92 spent the last three years of her restoration progress before being transported to Gore, and it was there that I first came face to face with K92. One option of moving the locomotive to Gore was by rail, and for this it needed a dimensional check to make sure it would fit through the tunnels and under the low bridges on that route, a task I had to carry out as part of my work responsibilities. While there were no clearance issues, it did eventually go to Gore on a road transporter.

2001 – PRESENT

In 2001 the Gully building was again vacated, this time for good as the site was desperately needed for an expanding shunting yard. But fortunately, recognising the curved roof matched a recently built hanger at Mandeville, I suggested it may be worth salvaging for reuse as a workshop for the fledgling rail project I had become involved with there. This duly happened, with the heritage significance of the trusses only coming to light some years later. Stage 1 of the workshop building has now been erected at Mandeville with a funding application about to be lodged for stage 2.

[Figure 15] The first set of trusses after cleaning and painting, ready for erection. Photo by the author.

[Figure 16] Stage 1 of the Gully building erected at Mandeville in 2020. The wrought iron trusses give the space an airy feel with minimal impact on the interior space. It is hoped the building can be completed in 2022. Photo by the author.

During cleaning and painting of the roof trusses, some intriguing marks were uncovered. These showed that the trusses comprised sets, with some having each truss end-joint numbered and a manufacturers mark stamped in some of them. Some of the angle irons clearly showed the rolling mills brand.

While it did not take long to work out which building they were originally from, I have not been able to trace their origin back to specific manufacturers in Great Britain. All South Island Government works were overseen by the Dunedin Office of the Public Works Department, (effectively the Headquarters for their Civil Engineers) and at the time under the control of William Blair. He will have approved the building design and arranged the ordering of any material that needed importing through the Agent General in London. He in turn will have called tenders for the various items requested and selected a supplier. With the Paint Shop being built in two stages, there will have been at least 2 separate tenders a few years apart. As it was a late decision to add a third bay to the Paint Shop, it probably left insufficient time to increase the order, so this third bay was most likely the bay that was built with a timber truss arrangement.

Careful examination of the trusses following sandblasting, shows little consistency in the marks. Other than the rolling mill brand in some of the angle iron, nearly all other marks appear to be assembly marks. The trusses are constructed from a Tee section for the curved top member, angles and flats for the diagonal members and rods with forged end-joints for the bottom members. With the many thousands of tons of railway material that required to be shipped to New Zealand, it is assumed that items like these will have been shipped in their individual pieces, requiring assembly on arrival. Manufacturers would then have applied markings to joints to aid assembly. The fact that there is little consistency would imply multiple manufacturers were used which would be common for urgent orders where one works was unable to complete the full order in the given time, so had another iron works fulfil part of the order. This would also account for the different dimension with at least two slightly different sizes having been identified.

The most obvious marks are at the joints at each end of the trusses. These are often numbered either with Roman numerals using a chisel, or a pattern of dots using a punch. Joints were numbered rather than trusses, with the numbers being consecutive on either end for those trusses that had them.

While one joint had all three members stamped, many joints had no visible numbers. This may indicate that in those cases the stampings are covered by the plate, as well as being on the back of the plate.

[Figure 17] Joint 12 with Roman numeral markings. Photo by the author.

[Figure 18] Joint 8 with dot pattern markings. Photo by the author.

[Figure 19] Joint 7 with dot markings visible on each member. Note the This is the opposite end of the truss that has Joint 8. Photo by the author.

[Figure 20] Possibly an Inspectors mark, only found on a few of these forked rod ends. Photo by the author.

[Figure 21] the Dorman Long brand rolled into some of the angle Irons. Photo by the author.

The one Iron Mill that is clearly identified is Dorman Long & Co of West Marsh, eventually a major player in the British steel industry and now absorbed into British Steel. Their brand is rolled into some of the angle irons that are used on the trusses, but no other Mill identifications have been found. Surprisingly, the top Tee section has no rolling brand.

> If my memory serves me right, Dorman Long were also the company that supplied the steel for the Railway Workshops reconstruction in 1927. Before long, only the buildings at Woburn in the Hutt Valley will still bear testament to that fact. Also in 1927, Dorman Long won the contract to build the Sydney Harbour Bridge, so by then a truly international company.

There is however one mark that stands out from others which has only been found in a very few locations and then in two different styles. It is assumed that it might be a later mark of William Barrows & Sons, owners of the Bloomfield Ironworks, Tipton. This is based on the initials W.B and the particular style of Crown accompanying one of the versions. While the iron Mill used BBH as the 'brand' letters (from an earlier company name of Bramah, Barrows and Hall), it is possible that the W.B was used for items manufactured to order. It is then also possible that the slightly different marks represent the two different orders, one from around 1875 and one from around 1880, with only a few items per order stamped this way.

[Figure 22 and 17] Two variations of a works stamp on a joint plate and on a tie-rod. Photo by the author.

[Figure 23] Advertisement from 1881 as found at Grace's Guides [14].

Very little history of iron mills is adequately recorded and the only paper I was able to find that addressed the subject of makers marks in any detail focused on structures in Belgium [46]. That author acknowledges there is little information available about British ironworks and their individual marks, implying that there is a lot of work that could be done in that area.

A number of factors have complicated the research into the origin of these trusses.

- The fact that they were sourced from a building that had already been re-erected on a new site, with no documented details of the original building available.
- the assumption that the trusses were all identical when they were recovered, so no records were kept of their relative position within the Gully building.
- Funding constraints meant that even now, not all the trusses have been sandblasted yet, meaning additional marks could still be discovered.
- The fact that many of these marks are assumed to be assembly marks and to discover them all would require disassembly of riveted joints, which is not viable.

Future research may yet be able to add to the knowledge gained so far.

CONCLUSION

As time now marches on through the 21st century, we have three items from the 19th century, manufactured many thousands of miles from where they now exist, still serving the purpose for which they were made. They have come together again through a unique set of circumstances with the express aim of displaying the varied skills required to individually create them, and it is truly hoped that they will be appreciated and acknowledged for what they are by all who visit them.

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REFURBISHMENT OF THE ROSS CREEK RESERVOIR

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Summary: The Ross Creek Reservoir is retained by a puddled clay core embankment dam constructed in the period 1865-67 to provide municipal water supply for the settlement of Dunedin, founded some 20 years earlier. This dam has recently undergone extensive refurbishment to enhance impoundment security and integrate the reservoir into the water supply resilience project for the city. Various deficiencies have been addressed, including construction of a rockfill buttress zone to enhance earthquake and flood resilience. While the engineering works have needed to satisfy modern dam safety requirements, efforts have been made to capture and retain heritage features wherever possible, and to sympathetically detail affected features.

Puddled clay core dam, High potential impact classification impoundment, dam safety deficiency mitigation, heritage retention

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DUNEDIN'S EARLY WATER CONUNDRUM

Dunedin and the southern part of the South Island experienced a significant boom in population following the discovery of gold in Central Otago in 1861. From its founding in 1848, Dunedin was quickly established as a city by the Scottish settlers, and the need for sanitary drinking water was soon realised. On the back of the Otago Gold Rush, Dunedin grew quickly, from about 2,000 in 1859 to 20,000 in 1864 [4, p.28], and health impacts were soon felt by way of waterborne illnesses.

In 1863, the initiation of serious dialogue for how to source and deliver clean water in Dunedin began and many reservoir sites were surveyed for suitability around the hills of Dunedin. Engineer Richard Wooley led the first experiment to obtain and retain water at Ross Creek as part of his attempt to establish a private waterworks company [5]. While Wooley was unsuccessful in his bid, he did identify Ross Creek as the prime location and encouraged the establishment of the Dunedin Water Works Company.

Shortly thereafter, Ralph Donkin of the Dunedin Water Works Company built upon Wooley's proposal to construct a dam on Ross Creek. The dam was proposed to be located at the head of a steepening gradient below a suitable impoundment basin with a catchment area of 3.84km^2 [4].

Offer describes the engineering of dams for public water supply *as "not undertaken without a great deal of engineering consideration and sometimes an equal degree of public controversy"* [4, p.27.]. At the time of the construction of the Ross Creek Reservoir over the period 1865 to December 1867, the Dunedin Council was in financial difficulty but recognised the necessity of a reliable water supply in Dunedin (ibid.). By 1875 the Dunedin City Council (DCC) had taken over the facility from the Dunedin Water Works Company.

Downstream from the dam, Ross Creek enters the Leith Stream (Water of Leith) that passes through the developed urban area, including the University of Otago campus, before discharging to the harbour.

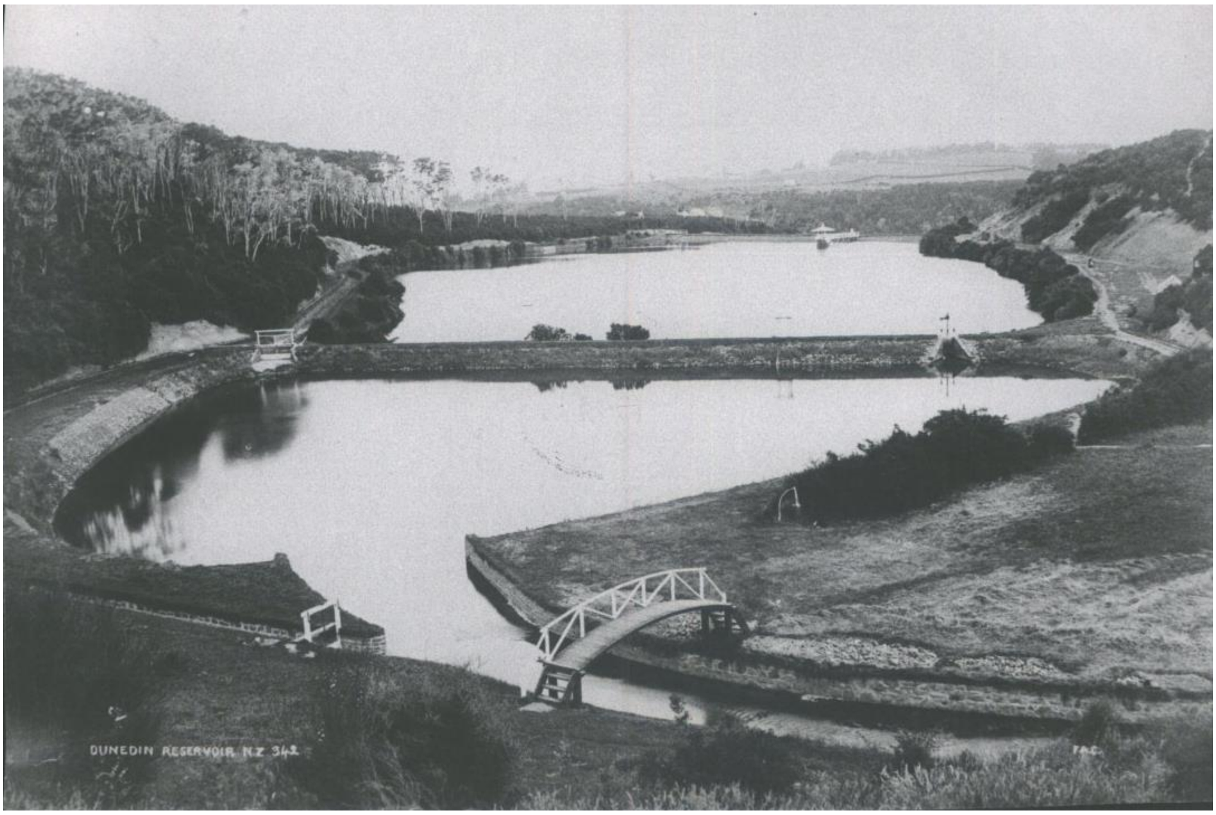
ENGINEERING HISTORY OF THE ROSS CREEK RESERVOIR

In 1865, the Otago Witness noted that Mr Ralph Donkin undertook a detailed survey of the district to identify an appropriate place for the reservoir [8, 2/9/1865, p.6.]. The natural topography was recognised as being well suited to the construction of a dam, including a good slope that fed into a natural basin. Donkin prepared the design of the dam and David Proudfoot was contracted to manage and deliver the construction programme.

There is a lack of reliable as-built records of the original construction, but various design option drawings were archived, some of which appear contradictory. Some drawings of later observations and alterations are also undated. However, research, site exposures, and knowledge gained during the refurbishment project have enabled much of the historical ambiguity to be removed. A masonry lined diversion channel was constructed in 1865 around the left flank of the proposed reservoir, passing close to the invert level of the proposed spillway cutting at the left abutment and discharging down a timber flume to a masonry stilling basin beyond the toe of the proposed dam. Stone pitching was laid in the invert of the diversion channel, and flow was diverted into this channel at the head of the proposed reservoir through the construction of a small embankment across the creek channel that formed a small upper pond. This pond also acted as a sediment trap and included a controlled release into the main reservoir.

Preparation of the weathered volcanic rock dam foundation included excavation of a key trench for the central puddled clay core. The 12" (305mm) diameter cast iron offtake pipeline and 9" (230mm) diameter cast iron scour line were laid on masonry pedestals in the vicinity of the true right bank of the creek channel through the proposed main dam footprint, terminating on the upstream end at the masonry offtake tower position that was built to house the isolating valves and drum screen. Minor local construction dewatering was able to be facilitated through the offtake tunnel works. The 27.5m high embankment was then constructed as a hydraulic fill operation utilising progressively placed small retaining bunds at the embankment shoulders. The finished shoulder nominal slopes were 3H:1V upstream and steeper 2H:1V downstream. The works were completed in 1867 with placement of stone pitching for wave armouring purposes on the upstream shoulder within the reservoir operating range, and at the left abutment spillway sill adjacent to the diversion channel [refer Appendix A]. The dam impounds some 250,000 m3 gross storage at full supply level.

The upper pond was soon found to trap excessive sediment in high flows, and alterations were carried out c1875 to remove sediment to dump, along with extending the true left diversion channel upstream and adding control gates at the intake to the upper pond.



[Figure 1] Early view of the extended diversion channel from the head of the reservoir towards the main embankment and offtake tower in the distance

Nine years after initial reports of serious leaks, Mr Hay, Town Engineer of Dunedin, reported to the City of Dunedin about a leak in the dam. The residents of Woodhaugh and surrounding areas raised concerns about the leaks in the area [5, p.204.]. Here, Hay identified water leaking at the dry-stone retaining wall at the toe of the embankment. This feature situated at the end of the wooden flume formed part of the Overflow Management System. Hay describes this wall as “built to prevent a slope of loose clay and boulders coming in contact with the water from the bye-wash shoot [spillway chute] that discharges into the stream-bed at this point” [7, p.6-8.].

[Figure 2] View looking upstream of the dry-stone wall at the stilling basin portion of the early overflow system following clearing of vegetation, dumped spoil and debris. Current spillway chute is to the right of this image.

This leak had three defined flows, a west, middle and east branch (ibid.). Hay excavated (with the help of labourers) a small stone-culvert behind the retaining wall. He noted that this "old artificial channel… must have been built not later than 1875, when the upper basin was constructed, and the material excavated therefrom tipped over the outer face of the main reservoir dam" (ibid.). Obstructions were found within the east and west branches, and once these were cleared out, water flowed freely.

Hay's 1886 investigation also explored the flow of water near the upper spillway when the reservoir was "full to about 46 ft". Hay stated that this water flowed from the main embankment under the well grouted spillway invert, which was grouted with cement and sand [7, p.7.]. He did mention that this was an "infinitesimal quantity" (ibid.). Hay also recommended that the scour pipe in the offtake tunnel was too small in diameter (9", 230mm) and could not perform its job properly. Another engineer, Professor Black from the University of Otago, also inspected the reservoir in July 1886. He came to similar conclusions as Hay about the most appropriate repair solution, although the scour pipe remained at 9" diameter, indicating it was not upgraded. It is noted that the 12" (305mm) diameter offtake line included provision for direct discharge to the rock bounded creek channel downstream of the dam.

In 1889, a telegram was sent to the Dunedin District Engineer, Edward Ussher, questioning the safety of the Ross Creek Reservoir in response to the core leaks in the vicinity of the creek channel [7]. Leakage data was supplied by Ussher in this report. Offer explains that this leak was acted upon with urgency due to a dam failure in the United States of America in the same year [4, p.30]. A series of reports that seemed to be for the purpose of appeasing the public were prepared, although many of these just highlighted the fact that company profits and cost saving tended to be of more importance than top-of-the line design [4, p.30]. Ussher's general conclusions of his 1889 report suggested that a new storm water channel should be installed (later, the true right storm water diversion channel) and that in summer the water should be lowered and the dam cleaned out. He called the dam perfectly safe if these recommendations were actioned [7, p.3.]. Access to inspect and repair the core defects was facilitated via adit and shaft excavations beneath the embankment downstream shoulder on the alignment of the original creek channel [refer Appendix B]. This repair work eventually extended to fully exposing the offtake pipelines within the embankment and constructing a concrete arch tunnel to remove any risk of pipe leakage contributing to seepage within the embankment.

Ongoing leakage is understood to have necessitated further water level lowering and repairs in 1903, although the specific nature of these repairs is not known.

In-service deterioration of the original timber spillway flume over some 60 years led to its replacement in 1926 with a steep structural concrete flume. This feature curved around the true left abutment and discharged to a stilling basin some distance downstream from the original masonry and dry-stone feature at the dam toe. It has been subsequently determined that the altered hydraulic entry conditions to the replacement chute increased the local contraction choking effect and adversely affected the available flood freeboard.

In March 1929, Dunedin experienced a significant storm event with 11” (280mm) rainfall in 24 hours recorded at Ross creek [10, p.4.], that resulted in extensive surface flooding in the developed Leith stream area of the city. It is understood that freeboard was lost at the Ross Creek dam crest at the peak of the storm, but no evidence of actual overtopping was reported.

Flood handling improvements were subsequently made in 1930 through the construction of the true right concrete lined storm water diversion channel that discharges to School Creek [11, p.6.]; a potential mitigation measure originally identified in the 1880s.

Gunite placement over original stone pitching was undertaken c1949, including the upstream shoulder wave zone and the upper spillway invert. This action presumably arose from ongoing leakage issues (although no specific documentation of the background has been sighted).

Ongoing high level left abutment leakage led to the installation of two shallow collector manholes and associated pipework downstream of the embankment crest in the mid-1970s [pers. comm]. The rate of high-level seepage from the left abutment was observed to be quite sensitive to the reservoir water level as it approached full supply level (FSL), leading to the FSL being lowered some 0.9m by the construction of a concrete lined rectangular slot through the spillway crest.

There has been a programme of progressive vegetation removal from the embankment since 2003. This work initially focussed on the removal of deep-rooted vegetation in the vicinity of the embankment crest.

The facility was still operating as a contributor to the city’s municipal water supply up until some 25 years ago when the treatment plant was decommissioned. The reservoir impoundment was retained within a reserve setting above the northern portion of the city centre that has provided a valued public amenity space.

Following a period of sustained rainfall in June 2010, a large tension scarp developed at mid-height in the downstream shoulder of the dam.

[Figure 3] View of head scarp on embankment shoulder after temporary stabilising fill was placed (investigations in progress)

Due to this observed instability, the DCC, as owner and operator, implemented a special management regime to apply within their dam safety assurance programme until such time as the future of the assets was determined. As part of this process the reservoir was lowered to 4.7m below the original spillway sill. This action ensured there was substantially reduced live storage present while the natural creek flow could be handled by the combined capacity of the left and right bank diversion channels. Significant flood flows could exceed this diversion capacity, allowing the reservoir to temporarily rise above the set control level. The reservoir was not fully dewatered due to the increased risk of causing desiccation damage to the hydraulic fill and puddled clay core.

Following this immediate response to the dam safety incident, the DCC carried out an extensive review of the facility, including consideration of possibly decommissioning the reservoir. The decision was made to retain it as part of the back-up water supply facility if problems arose with the security of the long delivery pipelines from Dunedin's main water sources at Deep Creek and Deep Stream. The amenity value of the suburban bush reserve setting was also a consideration. This decision led to the formulation of the Refurbishment Project.

SCOPE OF THE REFURBISHMENT PROJECT

The concept adopted for refurbishment primarily involved addressing the confirmed stability deficiency within the steeper downstream embankment shoulder. The opportunity was also taken to address other significant identified deficiencies where such action was compatible with this primary project objective and within budget provisions.

The planned physical works for refurbishment included;

- Enhancement of the static stability and seismic resilience of the embankment through the construction of several counterfort drains at the toe of the original embankment, followed by placement of a downstream compacted rockfill buttress and associated crest widening.
- Improvement in spillway flood surcharge and embankment freeboard through crest raising by the addition of mechanically stabilised earthworks (MSE), complete with an integrated new concrete crest wall and extension to the existing wave protection facing.
- Upgrading of flood handling capacity through the widening of the retained existing uncontrolled concrete spillway chute to improve extreme flood discharge performance standards.
- Ensuring grading compatibility at all accessible interfaces within the existing hydraulic fill through the provision of suitable filter zones and drainage relief paths.
- Constructing a new siphon pipeline at the right abutment for emergency dewatering purposes and to function as the inlet for the proposed Ross Creek to Mt Grand transfer pipeline.
- Decommissioning of the original offtake works including placement of a substantial isolation plug in the offtake tunnel but retaining the heritage masonry tower.
- Establishing a new surveillance monitoring instrumentation system suited to monitoring the performance of the refurbished works.
- Alterations / reinstatement of access tracks and raising of the existing footbridge over the spillway and true left diversion channel to suit the new earthworks profiles.

Geotechnical design and analysis aspects as they applied prior to construction and at consenting have been the subject of a previous technical paper [3].

This package of works was not intended to address all identified deficiencies at the reservoir, nor to necessarily achieve full compliance with current target engineering performance and resilience criteria applicable to high potential impact impoundments. Any residual deficiencies having a lower priority will be subject to appropriate attention within the owner’s ongoing dam safety management programme. This aspect was included in the Building Consent process [refer Appendix C].

REGULATORY CONTEXT

This site has been recognised by Heritage New Zealand Pouhere Taonga as the oldest of its type in New Zealand in recent use, with its only companion being the Karori Dam in Wellington [4]. The Ross Creek Earth Dam is listed [9] as a Category I Historic Place (List Number 4922) and is recorded as an archaeological site (I44/567). The Ross Creek Valve Tower is listed as a Category I Historic Place (List Number 4722).

Resource Consent to dam the water way was held by the DCC under consent 2002.314 issued in January 2005. Resource consent applications were submitted in December 2013 for the proposed refurbishment works, including aspects affecting the natural water course and water quality, along with the earthworks activities at the dam site. Resource Consent OUT-2013-5 was subsequently issued by the DDC, and Resource Consents RM13.469.01 and RM13.469.02 were issued by the Otago Regional Council in March 2014. The requirement for Authority under the Historic Places Act 1993 was highlighted in the consent conditions.

An archaeological assessment identified the Ross Creek Reservoir as holding high archaeological values in relation to the recorded archaeological site and the heritage listings associated with the dam [6]. It recommended that an archaeological authority be obtained to permit repair works to take place with emphasis on protection and retention of heritage features. Archaeological authority 2014/742 was issued to the DCC to undertake these works. Monitoring and recording of the works and any archaeological features were required under this authority.

Building Act: As the potential effects of uncontrolled release from the reservoir into the downstream urban environment are anticipated to be very significant, the impoundment accordingly attracts a HIGH potential impact classification (PIC) within the dam safety management framework. This rating dictates the engineering performance criteria targets that apply to the site in terms of flood handling capability and seismic resilience. Any shortfall in reliable performance expectations relative to these target criteria identify and quantify the deficiencies that require mitigation action. The NZSOLD Dam Safety Guidelines [1] were adopted as an Alternative Solution in the Building Consent application to alter the dam works submitted in May 2014. Building Consent DBA0062 was issued for the refurbishment alterations by the Otago Regional Council as Building Consent Authority in April 2016.

As the works were undertaken on a HIGH PIC impoundment, hazard management processes applying during the construction phase received close attention. Relevant aspects of the construction hazard management planning have been covered in another technical paper [2].

SELECTED FEATURES OF ENGINEERING HERITAGE INTEREST

Here, we will focus on a limited selection of key features that are interesting from both archaeology and engineering perspectives. This selection includes the exposure of buried embankment and buttress foundation features, including remnants of the timber flume along with drainage and leakage repair items, retention of portions of the original bluestone pitching in the upper spillway, and clarification of the background to defects in the upper core leading to improvements in their remedial treatment.

Buttress foundation preparation – wooden flume remnants

A number of heritage drainage features were exposed during the buttress foundation preparation, including ceramic pipes and rock lined drains, evidence of early leakage repairs, and an historic wooden flume remnant. The historic wooden flume is depicted on an original 1865 plan (290) by the Dunedin Water Works Company [refer Appendix A].

[Figure 4] Exposure of remnants of original 1865 timber flume. (Replacement 1926 concrete spillway in background)

Exposed timber fragments were established to be remnants of the original 1860s feature, not just a rejected design option which was an alternative interpretation of the ambiguous archived records. The construction methodology of dumping spoil down the embankment, likely from the excavations required for the upper pond upgrades and the replacement concrete spillway chute, resulted in several metres of the base of the kauri flume becoming buried and thereby remaining in the archaeological record.

This exposure established that the concrete spillway chute that was present (and in need of alteration to increase flood discharge capacity), was in fact an early 20th century replacement, and as such it was found to be reinforced rather than unreinforced.

The flume was built with kauri (*Agathis australis*) timber and was originally embedded in the yellow clayey silt embankment fill. Approximately three metres by one metre of the base of the flume was buried by later spoil material. The condition of the exposed wood was good considering its original service life of some 60 years and then being buried for some 90 years once it was made redundant by the construction of the replacement concrete spillway in the 1920s. The use of kauri in the wooden flume is notable. It fits with the 19th century favourability of kauri for utilitarian timber structures due to its strength and durability. The timber does not grow south of the Coromandel, so would have been imported into Otago. The remnant was not able to be retained in place, and the recovered material was offered to the Toitū Museum.

Buttress foundation preparation – evidence of historical leakage behaviour

Excavation to expose the buttress foundation required close attention to construction methodology and sequencing to address the need to maintain shoulder stability during such excavation [2]. Progressive exposure revealed extensive evidence of unrecorded original and subsequent relief drainage works associated with springs and seepage flows that had been experienced at both low and high level. These features included rock drains, ceramic pipes (typically 6” (152mm) diameter), cast iron and riveted pipes, and a rivetted flume. Many of the features were no longer operational, and with no filter protection being utilised in this era, many of the piped features were found to be clogged with clayey silt.

[Figure 5] View of various shallow drainage features exposed during buttress foundation preparation in vicinity of true left abutment, plus shallow collector manholes shown at left of image

Layout of the new filter protected relief drainage works was adapted to effectively intercept the identified sources and minimise the potential for local saturation of the AP150 rockfill buttress zone. This adaptation included the addition of a deep collector manhole below the true left abutment to separately intercept high level seepage and facilitate targeted flow and turbidity monitoring of relief drainage from this area.

Buttress foundation preparation – creek channel drainage features

Stability analysis of the hydraulic fill embankment under seismic loading revealed a high degree of sensitivity to the dynamic build-up of excess pore pressure at the toe in the vicinity of the infilled creek channel [3]. This situation led to the inclusion of several counterfort drains in this area in the scope of the refurbishment project.

[Figure 6] Buttress foundation preparation at creek channel showing basalt boulders

Exposure of the infilled creek channel at the toe followed the staged buttress foundation stripping activity, with further tight control on the construction methodology affecting stability.

It had been inferred during the refurbishment design phase that the creek channel under the embankment had originally been stripped of alluvial and/or colluvial material to expose the insitu weathered volcanic basement material prior to placing the original hydraulic fill. However, as excavation progressed in an upstream direction along the infilled creek channel towards the embankment toe, it became evident that the creek channel still contained a substantial quantity of very large basalt boulders overlying the highly weathered Andesite basement material. These boulders extended well below the level of the creek bed that had been inferred during design.

There were also records of major leakage repairs undertaken within the first 22 years of reservoir operation [refer Appendix B]. These repairs included gaining access to defects in the central puddled clay core through a series of small shafts and adits generally on the line of the creek channel under the downstream shoulder. Toe excavation within the creek channel during the refurbishment project exposed a section of an infilled adit, generally where indicated on the archived drawings of this 1880's repair work [refer Appendix B]. The infilled adit revealed a source of concentrated seepage that was investigated and found to be associated with a substantially clogged 6"(150mm) diameter earthenware open jointed pipe.

When cleared by jetting, this pipe was confirmed to extend upstream along the creek channel, possibly as far as the puddled core, but grout obstructions prevented the camera progressing to that extent. Makers marks on the pipes indicated they were dated from the 1860s, with some modifications from early 20th century. This suggests the drainage line may have predated the extensive leakage repairs of the 1880s, and the proximity to the investigation adit may simply be that both naturally followed the original creek channel. This finding led to a review of the relief drainage concept, as in the absence of filter protection, this drain effectively bypassed the proposed buttress filter layers and the proposed filter protected counterfort drains. Such filter protection is central to current embankment dam design, controlling the potential for internal erosion associated with seepage to progress uncontrolled to a failure condition. Rather than seal the existing drain (by grouting and affect the drainage relief paths that had been controlling the phreatic conditions in the shoulder in this vicinity), a second deep (12m) relief drainage collector manhole was added to replace the proposed counterfort drains. Inspection and isolation facilities accessible from the surface were included in this manhole, along with full time turbidity monitoring instrumentation to complement the downstream drainage flow monitoring .

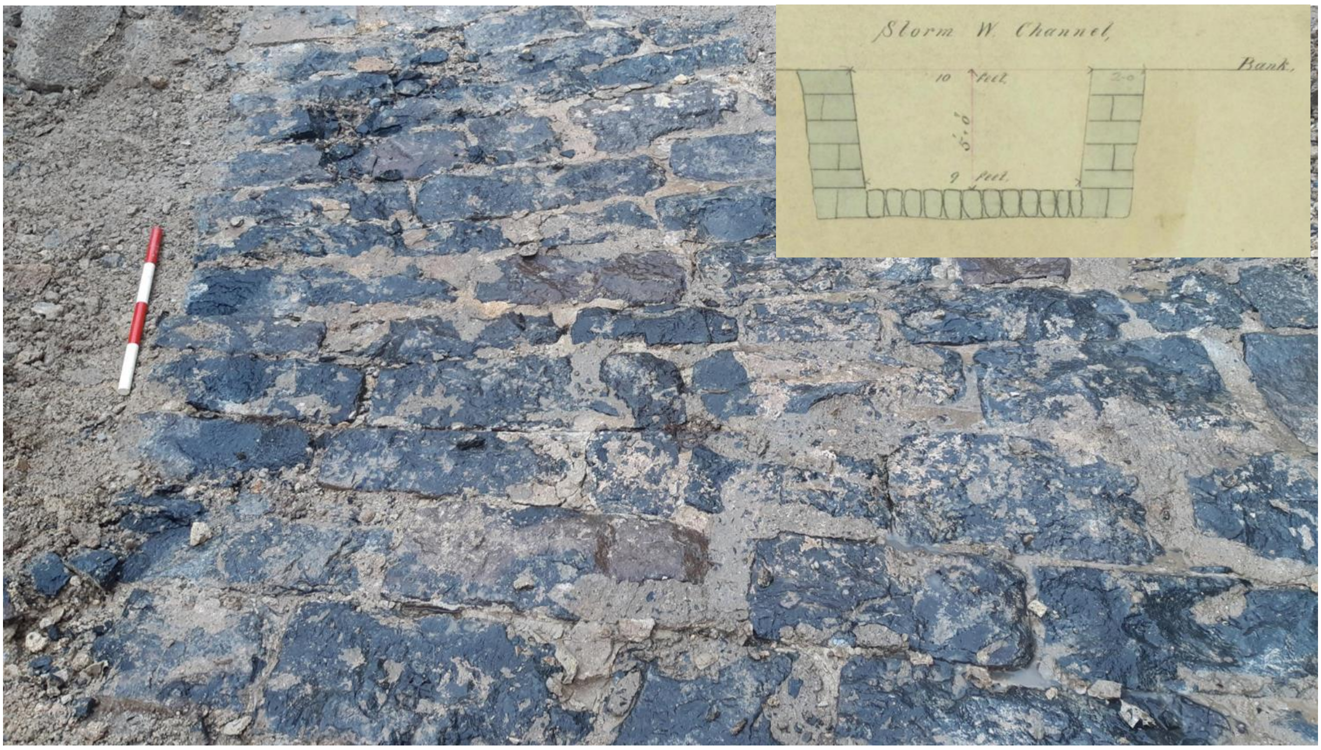
[Figure 7] Addition of western manhole to facilitate monitoring of discovered creek channel drain extending back to dam core trench

Bluestone pitching in the upper spillway

Improvements in our understanding of the historical sequence of alterations at this site clarified the basis of the poor hydraulic performance at the transition from the spillway crest and upper spillway into the concrete spillway chute. Namely, the geometry of the original masonry lining and associated hydraulic grade line profile had been adversely affected by the placement of a significant thickness of concrete and gunite over the original stone pitching in the upper spillway, thereby raising the invert approaching the replacement chute. It is of note that the replacement works had significantly compromised the hydraulic performance of the original design layout.

The use of bluestone pitching is notable. Bluestone sourced from local quarry sites was a common yet highly sought-after construction material in 19th century Dunedin. Its incorporation into the original 1860s construction showed willingness to ensure the integrity of key features using the best quality materials available at the time.

While the perpetuity of the discovered wooden flume remnant *in situ* was not possible, efforts were made to ensure the preservation of the bluestone invert. Engineering requirements meant that a small portion (less than 10%) of the stone pitching had to be removed. However, a collaborative approach and a redesign avoided the need to remove the entire feature. Recording of the unsafe portion of pitching prior to its removal was undertaken.



[Figure 8] Bluestone pitching exposed under later lining

Upper core defects

As introduced above, the refurbishment project included crest raising to increase spillway flood surcharge and freeboard. Significant seepage in the vicinity of the left abutment had been experienced for many decades when the reservoir was near FSL. The spillway slot constructed in the 1970s was used to lower the FSL and minimise this effect, but it was now important return the repurposed reservoir to its original operating level and associated live storage capacity. The design of the crest raising works included a small slurry trench cut off (or core extension feature) below the proposed concrete crest wall to intercept and seal possible crack defects that may have been present in the embankment crest area. Any potential rock mass defects present in the upper left abutment that may have been contributing to the seepage were to be treated through extending the new buttress filter layers sufficiently high to intercept any flow paths and thereby prevent the development of internal erosion.

Following stripping of the surficial crest cover in preparation for raising, clear evidence of core fill having been placed in a trenched upper core zone over the lower puddled clay core became apparent.

[Figure 9] Stripped dam crest exposing trenched core capping zone. Buttress placement to right of image has temporary cover extended over obscured new sand and gravel filter layers below

Concerns arose at this point regarding the likely differential stiffness properties of the lower and upper core zones. Potential for internal arching and hydraulic fracturing within the low stiffness puddled-clay core was identified. The demarcation limits of the upper core trench also led to review of the design position of the core extension slurry trench and the associated crest wall position.

During hydration of the slurry trench bentonite infill during April 2018, water was found to be leaking to ground in two primary locations without evidence of (at that time) an identified exit point. The leakage sites were near the true left abutment and close to the valve tower access footbridge abutment near the centre of the dam. Concerns regarding potential uncontrolled seepage within defects in the upper crest zone were raised upon receiving this knowledge, which spurred a comprehensive suite of geotechnical and groundwater investigations. The scope included:

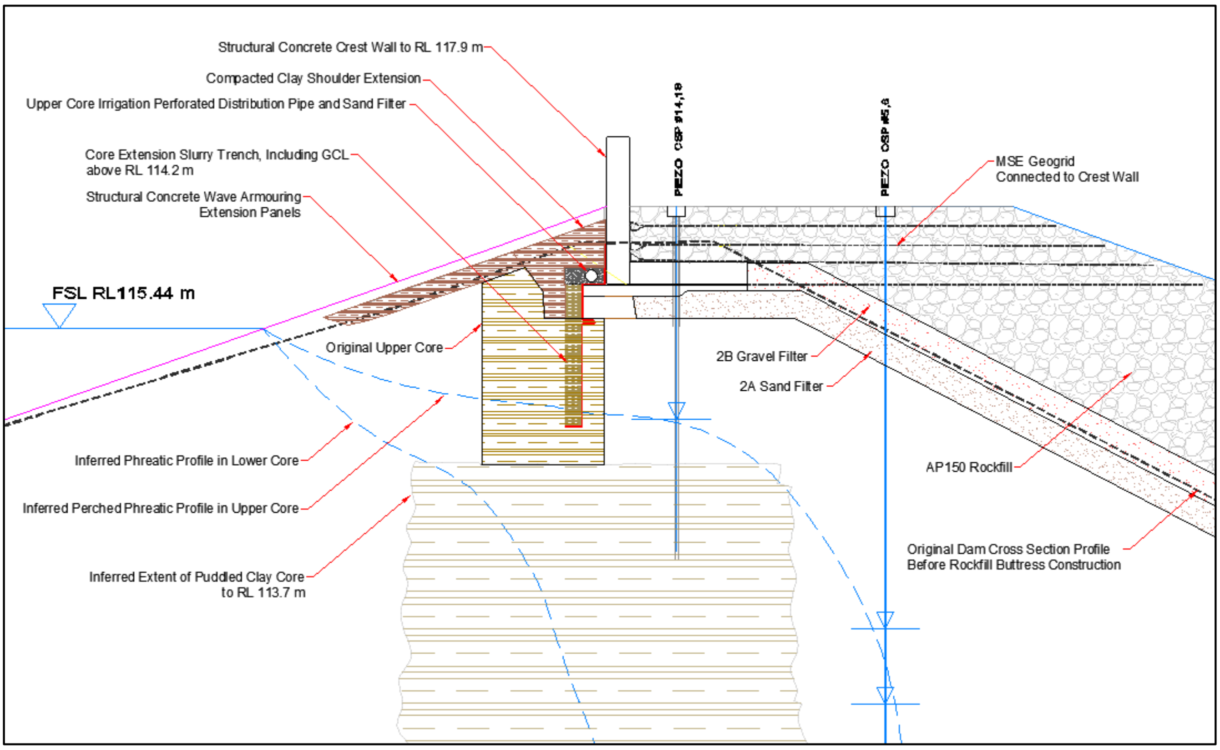
- Chlorine detection survey
- Dye tracing at cut off trench
- Dye tracer lost to reservoir near tower access bridge abutment
- Auger logs/DCT results at crest

No confirmed hydraulic connection to the downstream shoulder was identified, but direct connection to the reservoir near the tower bridge abutment was confirmed. The presence of core defects that appeared to be related to the interface between the upper trench infill core zone and the puddled clay core zone below was confirmed. A 6 year long consolidation settlement process within the puddled clay core under sustained lowered reservoir levels was interpreted from the intensive surveillance monitoring programme as the primary mechanism leading to the creation of lenticular core defects at the interface of the stiffer placed upper core arching over the lower core. i.e. even after some 150 years' service, and previous reservoir lowering events, the very low permeability puddled clay core was only normally consolidated at near full reservoir phreatic conditions. Remedial treatment in the form of a staged programme of cement and bentonite plastic grout placement in shallow holes augered from the crest was undertaken to seal the defects.

This interpretation reinforces the well-established need for caution when dewatering puddled clay core embankment dams.

Historical leakage behaviour under high reservoir water level conditions within 1m of FSL has been significantly improved by the deficiency mitigation works completed, but there is still evidence of remnant leakage behaviour. The mechanism may well involve a flow path within the true left abutment foundation associated with rock mass defect(s), as the scope of work in the refurbishment project did not include any foundation grouting treatment. However, safe operation at FSL is not currently compromised by this remnant leakage behaviour due to the erosion protection provided by placement of the engineered filter system at all potential seepage paths, along with targeted turbidity monitoring.

Remedial treatment of the upper core defects (including those identified during refurbishment), has been effective, although there is still evidence of local seepage paths being present at the top of the puddled clay core zone. The seepage paths are inferred to generate local perched water tables rather than drive the global phreatic conditions in the embankment. As already noted, filter protection is now present on these seepage paths.



[Figure 10] Crest raising cross section showing interface with original upper core (dashed line indicates original dam section)

Earthworks bunds placed to contain the original hydraulic fill and puddled-clay core were clearly identified during the refurbishment project as visually differentiated from the hydraulic fill material. However, the actual dimensions of these bunds and the effective width of the puddled core zone has not been well defined. The characteristics of source soils for the various hydraulic fill embankment dam zones have been shown to be very similar in terms of being moderately plastic (typically PI=23) clayey silt, that are differentiated primarily by their placement method.

SCOPE OF THE COMPLETED REFURBISHMENT WORK

The completed scope of the primary elements of the refurbishment project turned out to be very close to expectations. The as-built embankment stabilisation works and new offtake syphon quantities are tabulated below.

Table 1 Selected in place measures of refurbishment project as built quantities

Total stripping including topsoil and creek channel excavation	7,235 m^3.
Buttress foundation drains including collectors	300 m.
Sand filter for buttress	1,175 m^3
Gravel filter for buttress	1,193 m^3
AP150 Buttress rockfill	14,093 m^3
Offtake syphon pipeline	196 m

Construction phase changes from design expectations (further to those already presented above), included:

- Shortfall in recovered topsoil, resulting in deletion of the intended regrassing of the dam shoulder following buttress construction,
- Refurbishment rather than decommissioning of the gravity offtake system, but not to the standard of resilience required for emergency dewatering purposes,
- Automation of surveillance monitoring instrumentation and emergency dewatering syphon controls
- Replacement rather than repair of two deteriorated pedestrian bridges over the spillway
- Addition of various landscaping works including fencing and masonry walls

Where practical, added landscaping works were detailed to be sympathetic to the heritage features at the site. Masonry blocks recovered from site were utilised as facing to altered retaining works, and crest fencing details where matched to the original offtake tower access bridge railing.

[Figure 11] View of bluestone facing on the raised spillway wall utilising material recovered from site during the project

CONCLUSIONS

Refurbishment of the repurposed Ross Creek Dam has enabled continuation of its service life beyond 150 years and has highlighted several challenges associated with this form of heritage engineering. In particular, the application of archaeological expertise has effectively addressed the lack of reliable early construction and repair records needed to complement recent site investigations and adequately understand the current behaviour of the dam and its susceptibilities. We have also found that repairs and alterations undertaken over the life of the dam have not always been undertaken in a manner that has complemented the original design. Detailed documentation of our discoveries and refurbishment records will hopefully be of significant value to the ongoing safe management of the facility.

Despite the primary objective of the project being the mitigation of identified dam safety deficiencies, heritage features have been preserved where possible, and thoroughly recorded where they have needed to be disturbed.

A sensitive approach has needed to be taken to the significant alterations to the heritage works due to their construction many decades before the engineering discipline of soil mechanics was introduced. This has included utilisation of continuous monitoring and automated alarm triggering at critical times during construction. Intensive performance monitoring revealed that dam took some 6 years to reach a new state of equilibrium to the reservoir lowering following the 2010 stability incident. This knowledge informed the planning of the very gradual intensively monitored 18 month staged recommissioning programme used to return the facility to its fully operational state.

ACKNOWLEDGEMENTS

We would like to thank both DCC and WSP for permission to present this paper, and to acknowledge the team who contributed to this project, including Downer as main construction contractor and Peter Foster of Stantec in his capacity as independent peer reviewer in accordance with the NZSOLD Dam Safety Guidelines.

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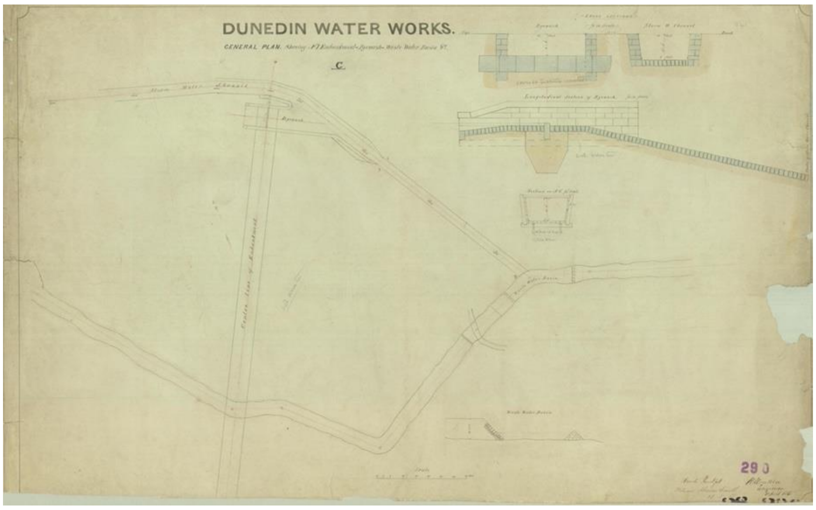
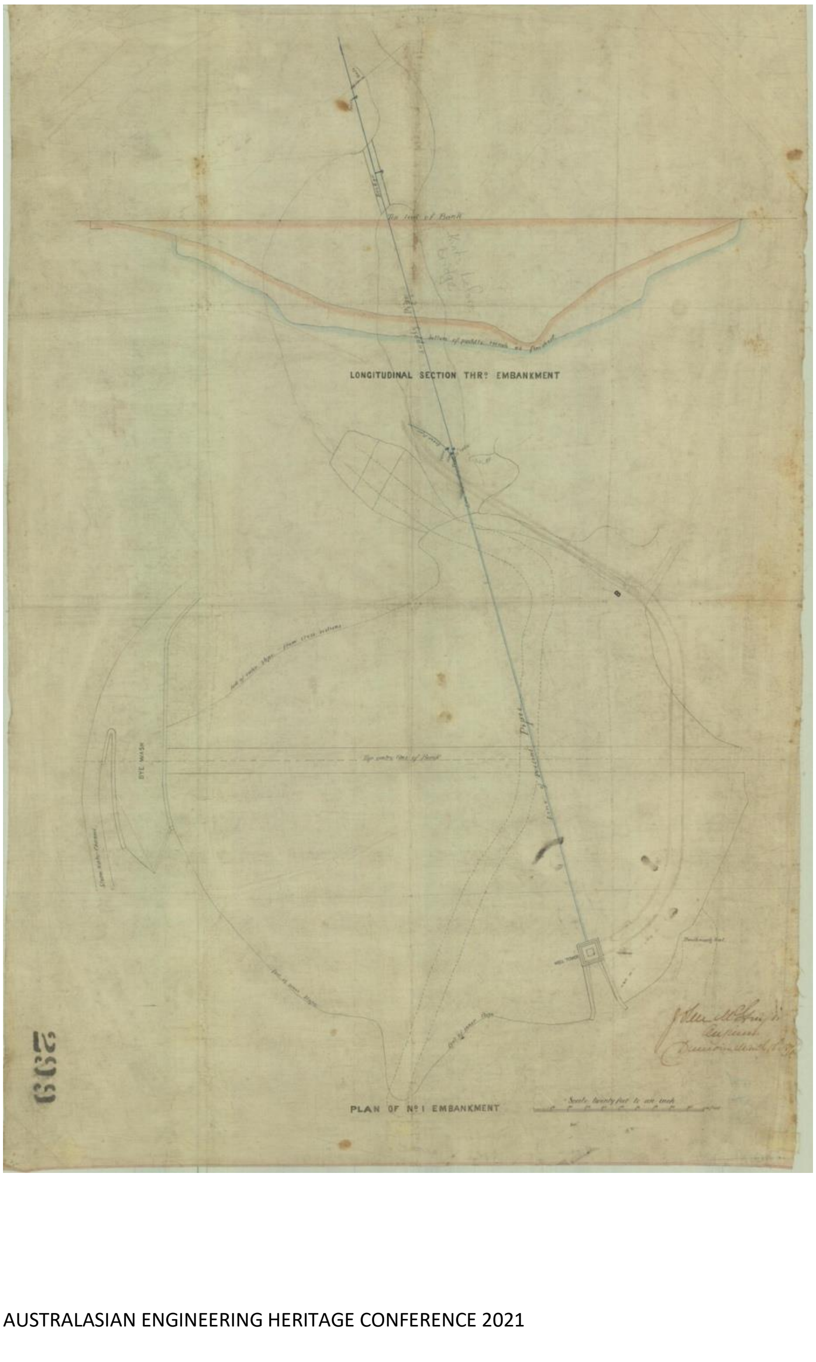
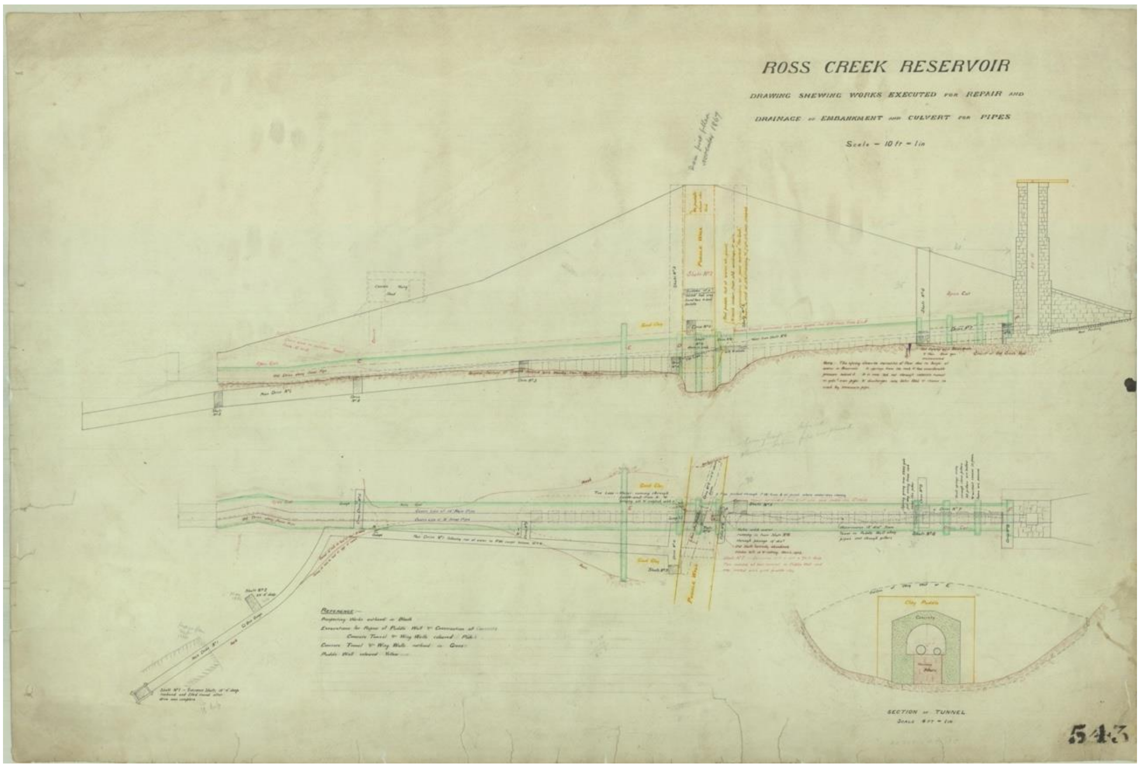
APPENDICES

Appendix A – Selected 1860s archived DCC drawings

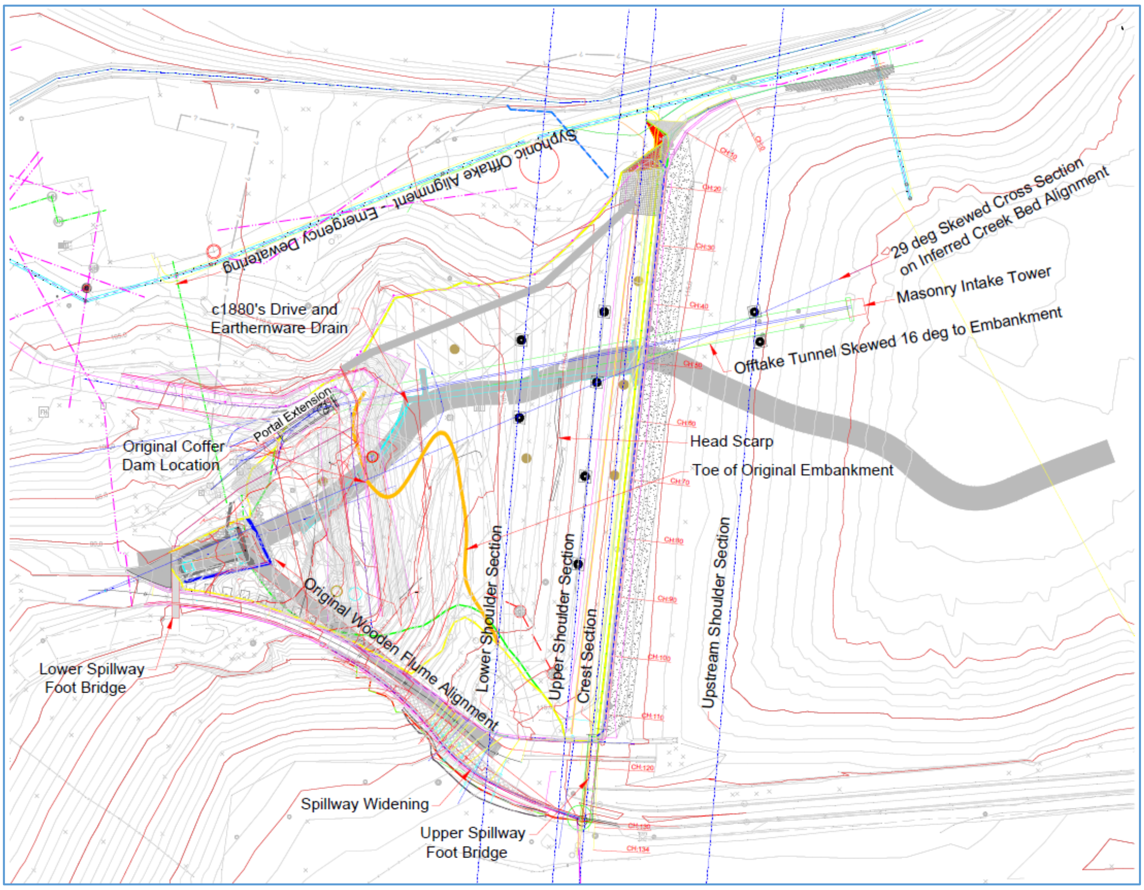




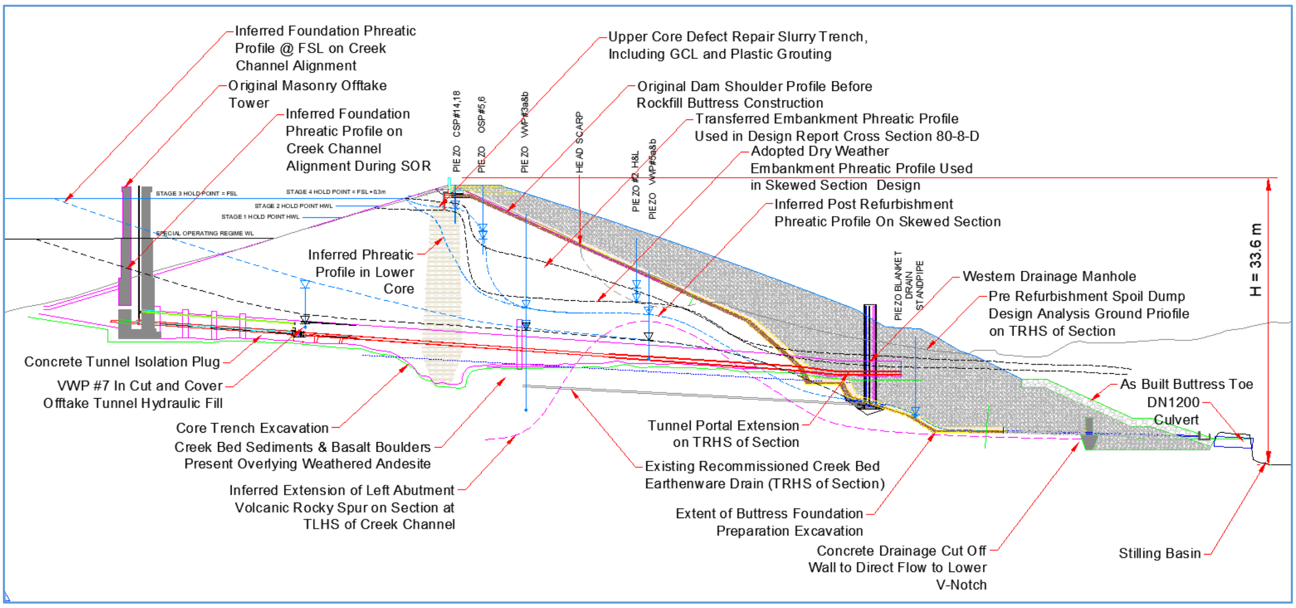
Appendix B – Selected 1880s archived DCC drawings



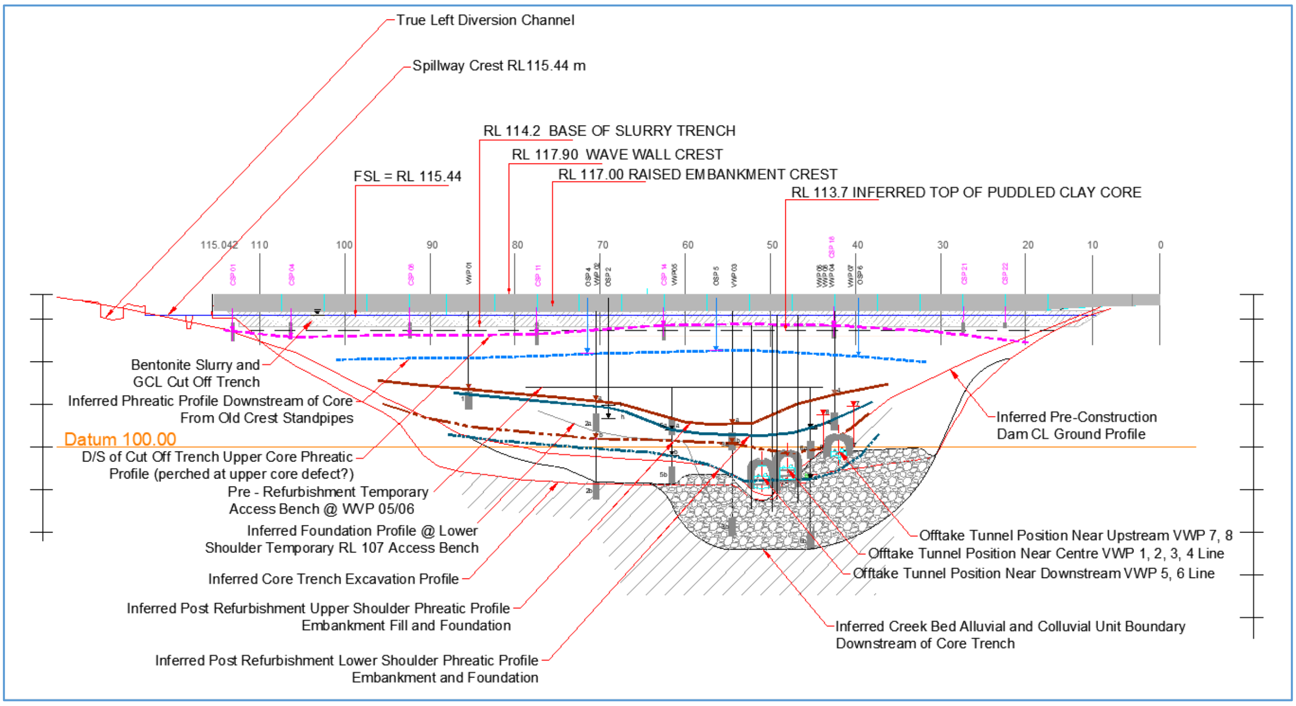
Appendix C – Selected refurbishment drawings.



[Figure C-1] Plan View of Refurbished Dam Showing Phreatic Features and Section Lines plus inferred creek channel



[Figure C-2] 29 degree Skewed Embankment Cross Section Showing Design and As-Built Phreatic Profiles Tunnel at 13 degree skew to section



[Figure C-3] Embankment Long Section Showing Post Refurbishment Phreatic Profiles on Multiple Overlaid Sections

ADDITIONAL PAPERS

engineering new zealand HERITAGE

ADDITIONAL PAPERS: WRITER BIOS

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REVITALISING CANALS AND COMMUNITIES IN YORKSHIRE – APPLICATIONS FOR AUSTRALASIAN INITIATIVES

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Summary: Britain's canals were integral to the mechanisation of mills and other industries during the Industrial Revolution (c. 1760-1840), and offer a unique window into that country's technical heritage. During 2020, there were over 385 million visits across Britain's 3,200 kilometres of navigable waterways.

The North Pennine Ring was restored in stages from the 1980s, reopening as a complete loop in 2002. This paper explores how revitalisation has created much-loved facilities for the economic, social, mental and physical wellbeing of individuals and communities.

The paper also explores how lessons from this canal restoration experience compare and can inform technical heritage initiatives in Australasia.

North Pennine Ring; canal; engineering heritage; industrial heritage; wellbeing; lock; towpath; heritage revitalisation; Knostrop Weir

THE NORTH PENNINE RING

The North Pennine Ring is a 296-kilometre-long canal network in the West Yorkshire, Greater Manchester and Lancashire regions of Northern England. It utilises 215 locks to traverse the Pennine Hills, connecting Leeds, Castleford and smaller settlements with ports at Manchester in the west and Goole in the east.

The Ring includes sections of five distinct canal navigations – Bridgewater Canal (opened 1761, extended 1762-65, completed 1776), Leeds and Liverpool Canal (first used 1774, completed 1816, extended 1822), Aire and Calder Navigation (first used 1704), Calder and Hebble Navigation (opened 1770) and Rochdale Canal (opened 1804, closed 1952, restored and reopened between 1996 and 2002).

Bridgewater Canal

Britain's canals were integral to mechanised development during the Industrial Revolution of c.1760-1840. Sankey Canal was the first canal built during this period, opening to transport coal between St Helens and the River Mersey, near Liverpool, in 1757. Bridgewater Canal was the second canal completed and, with its many complex and ingenious feats of engineering, it was this waterway that was celebrated as the first great achievement of the canal age. It ushered in Canal Mania, a period of intense canal building in Britain and Wales between the 1790s and 1810s.

Bridgewater Canal was commissioned by Francis Egerton, 3rd Duke of Bridgewater, to transport coal from his Worsley mines to Manchester. It was later extended and now connects to the 58-kilometre-long Manchester Ship Canal (opened 1894), which is a manmade inland waterway connecting the Port of Manchester with the Irish Sea. Bridgewater Canal is carried over the Manchester Ship Canal via the Barton Swing Aqueduct – a movable navigable aqueduct designed by English civil engineer Sir Edward Leader Williams (1828-1910) and opened in 1894. The structure is the first and only swing aqueduct in the world.

Bridgewater Canal has remained navigable since it was built but has only been accessible for pleasure craft since 1952. The canal faced intense commercial competition from both the Liverpool to Manchester Railway (the world's first intercity railway, opened in 1830) and Macclesfield Canal (completed 1831).

The Leeds and Liverpool Canal

The Leeds and Liverpool Canal connects Liverpool and Leeds through the major industrial region of Lancashire over a distance of 204 kilometres, including 91 locks. It was designed by engineers John Longbottom (d. 1801), James Brindley (1716-1772) and Robert Whitworth (1734-1799) and was built to transport coal, textiles and limestone for construction and agriculture.

The Leeds and Liverpool Canal took almost fifty years to complete and is the longest canal in Britain built as a single waterway. It remained commercially viable and open throughout the 19th and 20th centuries. The most important cargo in the early years was coal, later matched in importance by cotton, wool and finished fabrics.

The Aire and Calder Navigation

The Aire and Calder Navigation is a canalised section of the Rivers Aire and Calder built to provide a navigable link between Leeds and the Port of Goole. The Wakefield Branch, which extends the navigation 12 kilometres from Castleford Junction to Wakefield, provides an essential connection between the Aire and Calder and the Calder and Hebble Navigations. The Aire and Calder Navigation is 55 kilometres long and includes 16 locks. It still carries a significant amount of commercial shipping in addition to recreational boating traffic.

The Calder and Hebble Navigation

The Calder and Hebble Navigation is 34.4 kilometres long and includes 27 locks. It was built to extend the navigability of the Calder River upstream from Wakefield to Sowerby Bridge. Both this Navigation and the Aire and Calder include river sections along with sections of man-made canal. Locks connecting directly onto rivers are fitted with gauge boards to indicate whether the river level is low, normal or in flood and whether the river is navigable or not at any given time.

The town of Sowerby Bridge is at the junction of the Calder and Hebble Navigation and Rochdale Canal. Rochdale Canal is only accessible by short vessels, meaning longer vessels plying the Calder and Hebble Navigation must stop to unload, store, and transfer their cargos to shorter boats at Sowerby Bridge Wharf.

[Figure 1] Fisherman, Calder and Hebble Navigation

Rochdale Canal

Rochdale Canal was built to provide a navigable connection between Sowerby Bridge and Manchester. The route originally included 92 locks, but Locks 3 and 4 were replaced with a single deep lock in 1996 – Tuel Lane Lock – which has a fall of six metres and is the deepest canal lock in the UK.

[Figure 2] Tuel Lane Lock, Sowerby Bridge, Rochdale Canal

Restoration Timeline

The North Pennine Ring was restored in stages from the 1980s, reopening as a complete loop in 2002. Revitalisation of the Ring has enhanced wellbeing via accessible waterways, towpaths and canal-side amenities (including for more deprived communities), boosted historical tourism and employment (e.g. lock gate manufacture), and revitalised environmental protection and flood mitigation (particularly at Leeds).

Many of Britain's canals closed from around the mid-19th century due to competition from railways from the mid-1800s and roads during the 20th century. There were flow-on impacts from large-scale changes in patterns of industrialisation and land development. Defunct canals were occasionally converted for use by railways, but many became wastelands.

On the North Pennine Ring, unusually, most canals remained navigable and commercially viable, and were never closed. But the two steep canals that cross the Pennines between Yorkshire and Manchester – Rochdale Canal and Huddersfield Canal – did close, meaning that instead of a loop, the waterway became a horseshoe route. Sowerby Bridge and Manchester became ends of the line.

Huddersfield Canal

Huddersfield Canal (completed 1811, closed 1944, restored and reopened in stages in 1981, 1987 and 2001) connects Huddersfield with Manchester over 32 kilometres, including 74 locks. It is not technically part of the North Pennine Ring, but provides an alternative route for canal and canal-side users of the Ring navigation. The canal also includes the impressive 5,189-metre-long Standedge Tunnel (completed 1811) – the longest canal tunnel in the United Kingdom. The tunnel has never had a towpath and is not accessible to pedestrians (boats were 'legged' through in the old days). It is only accessible to narrowboaters at certain times in either direction and only with a compulsory chaperone on board.

ACTIVE AND PASSIVE WELLBEING FEATURES

Towpaths

Towpaths were integral to the development of canals in the 1700s and early 1800s, being used initially by horses and people to tow boats in the days before mechanised propulsion, and also as service lanes for narrowboaters to access village services, load and offload cargo, and operate locks and other navigation features.

Towpath refurbishment has been one of the first improvements made along many revitalised canals – particularly where there is potential for people to access natural spaces for exercise, fishing, feeding ducks and swans with young children, and other simple recreational activities.

[Figure 3] Tractor, swan and towpath at Riddlesden, Leeds and Liverpool Canal

Bridgewater Way

Bridgewater Way on Bridgewater Canal in Greater Manchester is a recent canal-side regeneration initiative to upgrade 65 kilometres of canal towpath, create 130 new and improved towpath access points, and widen the towpath for cyclists. The towpath corridor is also being made safer and more appealing. It provides a green link between arts, heritage and community facilities and attractions. Staged work on the project commenced in 2004 and is now nearing completion.

The Bridgewater Way project springs from an earlier canal refurbishment project, which resulted in the waterway part of the canal corridor becoming well-used and properly maintained. The new towpath forms part of a national cycle and footpath network.

One important outcome of the Bridgewater Way initiative is that it provides long-overdue access to green space to facilitate healthier lifestyles for some of Britain's most socio-economically deprived communities. Prior to the upgrade, towpath access points were difficult to find, lighting was poor, and cycling was not allowed. The towpath was also poorly surfaced in urban areas.

Bingley Five Rise and Three Rise Lock Staircases

On the Leeds and Liverpool Canal, the most well-known heritage structures are two impressive staircase locks at Bingley. The Bingley Five Rise Locks was opened in 1774 and was built to raise the canal eighteen vertical metres. It is the steepest lock staircase in Britain. A second lock staircase, the Bingley Three Rise Locks, is a short distance downstream.

The Five Rise is operated by the lock keeper. The basin at the top of the structure provides a popular stopping point for narrowboaters to moor, take on water, enjoy the view, and walk or cycle into Bingley for a pub lunch. There is also a canal-side café adjacent to the mooring.

[Figure 4] Bingley Five Rise Staircase Lock, Bingley, Leeds and Liverpool Canal

Because of its historic importance and its wonderful aesthetic, the Five Rise attracts photographers, the curious, towpath walkers and cyclists, and school children on school visits to learn see how the locks work. This is history in action – not just another statue or crumbling ruin. To best understand the locks and enjoy them, they need to be seen in action.

Central Leeds

At Leeds, the waterway provides a focal point for pedestrians and businesses. There are also two mooring basins – Granary Wharf and Leeds Dock. At Granary Wharf, there is a 4-star hotel, boutique eateries and bars, and office and retail accommodation, and Leeds Railway Station is adjacent.

There are two locks on either side of Granary Wharf basin, which provide points of interest. From a landing stage immediately downstream from Lock 1 – River Lock, a water taxi provides a convenient – and free – transfer service between Granary Wharf and Leeds Dock.

[Figure 5] Water Taxi at Leeds Dock

Waterside towpaths provide easy and pleasant access for pedestrians and cyclists (including narrowboaters with bicycles on board) from central Leeds to the canal-side Leeds Industrial Museum at Armley Mills and other city locations. One advertised option is a 21-kilometre towpath route from central Leeds to Kirkstall Abbey and on to the historic town of Shipley, where a train can be caught to return to Leeds.

Adjacent to Leeds Dock are the Royal Armouries Museum, urban parks, an automated working lock, redeveloped residential and office accommodation, a hotel, cafes, supermarkets and recreational facilities.

The Leeds and Liverpool Canal ends at Granary Wharf. The route downstream from there is the River Aire section of the Aire and Calder Navigation.

Leeds Flood Alleviation

The River Aire threatens Leeds with its floodwaters from time to time – notably during the devastating Boxing Day floods of 2015 when more than 650 businesses were flooded.

In 2016, Leeds City Council implemented a £162 million flood alleviation scheme for protection against future 1-in-200 events. The first phase, completed in 2017, involved construction of movable weirs, flood walls and other improvements to protect 500 businesses and 3,000 homes. Work began on the second phase, upstream from Leeds, in January 2020.

The new flood mitigation measures also improve river and canal access via a network of pathways, pedestrianised bridges and pocket parks. The new infrastructure is often a point of interest in its own right, for example the visually and technically interesting flood protection features lining the riverside districts between Granary Wharf and Leeds Dock.

Of the many new flood protection improvements, Knostrop Weir is most notable. Opened in October 2017, Knostrop Weir and the similar Crown Point Weir near Leeds Dock are the first mechanical flood protection weirs in the UK. They have bottom-hinged steel plates supported by bladders that inflate or deflate as required to control the river's level. Knostrop Weir also has an integrated footbridge which forms part of a 12-kilometre river/canal-side path between Leeds and Castleford. The weir and footbridge are evidence that engineering heritage can be beautiful as well as functional, and that heritage can be for future focused as well as from the past.

[Figure 6] Knostrop Weir and Bridge, Aire and Calder Navigation

Downstream from Leeds, land alongside the Aire and Calder Canal is used by industrial and commercial businesses, the historic Thwaite Watermill Museum, residential villages, and for regenerating green space habitats for wildlife, including otters.

Skipton – A Market Town

Upstream from Leeds, the Leeds and Liverpool Canal flows through Skipton, with a small basin with canal-side moorings, a pocket park and a café, plus additional moorings adjacent to the shopping precinct. The town is a base for canal boat hire companies, with many people hiring boats for day or weekend excursions. There are many vantagepoints from which to enjoy activities on the water, towpaths for walking, and waterside eateries.

On the western edge of the town, there are small swing bridges for narrowboaters to operate. Here locals and visitors cross paths, if only briefly. At more obstinate bridges, locals will offer to pitch in and help – providing another opportunity for social interaction.

[Figure 7] Towpath pedestrians at Skipton, Leeds and Liverpool Canal

Chantry Chapel and Hepworth Gallery

At Wakefield, where the Wakefield Branch of the Aire and Calder Navigation connects with the Calder and Hebble, attractions adjacent to the canal mooring include the sole surviving medieval Chantry Chapel of St Mary the Virgin, licensed in 1356, and the iconic Hepworth Wakefield gallery which opened in 2011. Water is a feature of the gallery's exterior design and the views from within.

Ubiquitous Features

Other elements that improve people's wellbeing on and around the North Pennine Ring include the pace of travel and the ability of narrowboaters and walkers to easily connect and converse. This can take place at locks and bridges where boats must stop before proceeding on, but also while underway on the water, when the speed of travel can be little more than walking pace on busy or winding sections. This allows people on the towpath to converse with narrowboaters as both travel alongside one another for a period of time. Many people walk the towpaths for a day or weekend excursion, returning home via train.

[Figure 8] Daytrippers at Redman Swing Bridge, Kildwick, Leeds and Liverpool Canal

CASE STUDY: LOCKS

Locks are special features in the canal landscape. They provide a useful way to examine how engineering heritage sites and trails can be attractive to visit, and how features contribute to individual and community economic, social and mental wellbeing. Canals vary in the number of locks along their length, with the North Pennine Ring having more locks than most. Locks also vary considerably in terms of the types of lock mechanisms used to operate them.

Locks create compulsory stopping points for narrowboaters. They must be successfully operated and passed through in order to proceed on. At minimum, a lock stop involves entering the lock chamber, closing the first gate, filling or emptying the chamber, and opening the second gate for departure. Stops can take much longer when a narrowboater must wait for other boats already in the lock, or when a chamber needs to be filled or emptied prior to entry.

[Figure 9] Towpath, Calder and Hebble Navigation

For pedestrians and cyclists, locks provide focal points at which to pause, take in the surroundings and learn how engineering features work. An interesting anomaly of the locking experience is that locals, who are typically towpath users, tend to learn about locks in action from narrowboaters, who are usually visitors.

For both on- and off-water users, locks are places where people naturally tend to gather and enjoy social connection.

Some locks – e.g. the Five-Rise and Three-Rise Staircases at Bingley – are operated by an onsite lockkeeper. These lock staircases take longer than a single lock to travel through – longer still if the lock is set against you and you must wait for other boats to complete their journey. The positive of this compulsory delay is the opportunity it provides to pause, connect, reflect and take in the enormity of the engineering achievements of an earlier age.

Canal Development – Contour Cutting versus Cut and Fill

The development of Britain's canals involved two main approaches to traversing the landscape – **contour cutting**, and **cut and fill**. Contour cutting was the earlier method, favoured by Derbyshire-born and largely self-taught civil engineer James Brindley (1716-1772). The cut and fill construction method developed as a result of later technological advancements, and was the preferred approach for Scottish-born civil engineer Thomas Telford (1757-1834).

[Figure 10] Salterhebble Top Lock and Keeper's Cottage, Calder and Hebble Navigation

Contour cutting follows the natural levels in the landscape and requires considerably less expense and technology to implement. The downside is that canals built this way tend to meander, and although there are few obstructions to delay passage, distances travelled can be considerable in comparison to 'as the crow flies'. Cut and fill takes a more direct approach between destinations, with hills cut and embankments built to level out the route. Capital costs are larger, but travel times are shortened.

Lock Development

The addition of locks on man-made waterways came about as a result of the British industrial revolution of the 13th century, when water-power developments led to important innovations in the mechanisation of processing for the woollen industries (e.g. fulling mills), flour mills and others [6]. Millers relied on river water to turn waterwheels to power their mills. They built weirs across the whole width of a waterway to ensure a steady supply of water. This, of course, created obstructions for cargo and passenger watercraft.

The solution was to develop the **flash lock** – essentially a gate let into a weir and opened by raising vertical planks. The release of water created a 'flash' that boats could ride down. Craft wanting to travel upstream were hauled through with a winch and rope.

[Figure 11] Windlass and lock mechanism at Salterhebble Guillotine Lock, Calder and Hebble Navigation

The next development was the **pound lock**, which has become the standard lock. Constructing two sets of gates at either end of a small section of canal creates a safe chamber within which a boat can gently transition between canal sections with higher and lower water levels. The chamber is filled and emptied like a bathtub, and the dangerous 'flash' removed.

Lock Operation Mechanisms

On the North Pennine Ring, each canal or navigation was designed and built by different developers and engineers. As a result, each has its own distinctive quirks and characteristics – including different lock mechanisms. This is part of what makes the Ring so interesting.

Locks are filled and emptied using **gate paddles** (openings with movable covers set into the lock gates) or **ground paddles** (openings set into the sides of the lock chamber itself). Each canal on the North Pennine Ring uses different mechanisms to operate the paddles.

One of the simplest lock mechanisms is the '**Jack Clough**' on the Leeds and Liverpool Canal. These are paddles attached to long handles, which work as levers to move the paddles.

[Figure 12] 'Jack Clough' lock mechanism at Higherland Lock, Leeds and Liverpool Canal

The most common mechanism is a **simple ratchet** turned using a windlass (or portable metal handle). This fits onto a ratchet spindle to raise and lower the paddle. This system also provides instant visual indication as to whether the paddle is lowered or raised. There are also **box cloughs** on some locks on this canal around Gargrave.

The Calder and Hebble Navigation is unusual in that it requires a **handspike** (a length of 5-by-10-centimetre timber shaped at one end) in addition to the windlass to operate the mechanisms along its length. The handspike is used to lever open simple lock gear which in turn lifts the paddles.

[Figure 13] Handspike and lock mechanism at Kirklees Low Lock, Calder and Hebble Navigation

On the Aire and Calder Navigation, where many lock chambers are large enough to take a ship, lock mechanisms are **automated**, requiring just a key and the press of a button to operate. This ensures they are safe for all.

Locks as Living Heritage

Locks are engineering heritage in action. They are hands on places where narrowboaters, pedestrians and cyclists stop and interact. Locks offer opportunities to learn how locks, lock mechanisms and canals work, and to operate the technology.

Towpath users can visit locks and enjoy them as places of interest when not in operation, but when narrowboaters are using the technology this adds another dimension of interest and understanding.

Locks lend themselves to a shared experience – people like to assist with opening gates or operating winding gear. The slower pace at which lock technology works also helps to provide opportunities for people to connect.

Locks can be appreciated on various levels – for their aesthetic interest in the landscape, as hands on and functional engineering heritage, and as a way of understanding the 'how it works' of the technology.

Locks facilitate opportunities for interaction between visitors and locals. They are also places for learning about engineering heritage technologies in action. Locks also provide an experience that is totally absorbing, and which involves cascading water – both good for wellbeing.

[Figure 14] Box clough lock mechanism, Bingley Five Rise Lock Staircase, Bingley, Leeds and Liverpool Canal

Locks require canal users to stop at specific locations to operate the locks (or, at Bingley, to help with lock operation). This provides opportunities to inspect and appreciate lock workmanship. Narrowboaters often meet canal volunteers and local walkers or visiting school groups at locks, and while waiting for a lock to fill or empty have the opportunity to engage in conversation. In addition, while locals may regularly walk to locks as destination points or past locks while using towpaths, it is only when canal users are operating the locks that the technical history of the structures comes alive.

APPLICATIONS FOR AUSTRALASIAN INITIATIVES

There is a growing interest engineering heritage in Australasia. Both Australia and New Zealand are experiencing a growth in initiatives to share heritage stories and explain how features work.

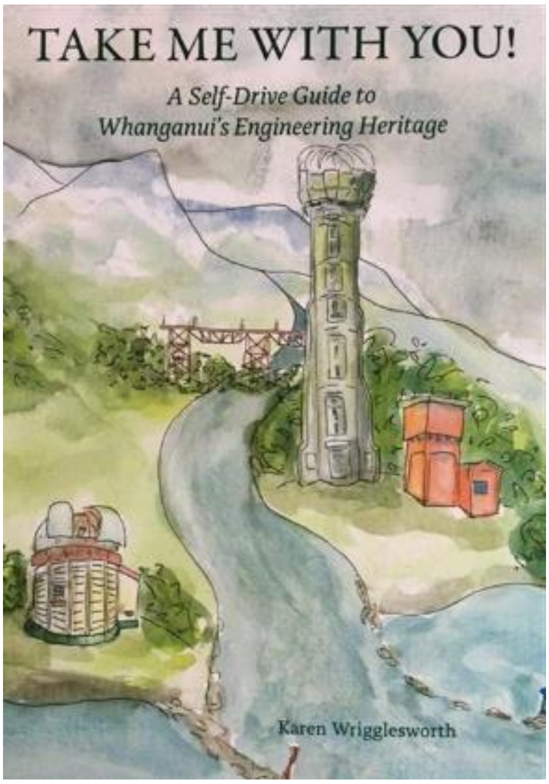
Examples of Australasian Initiatives

In New Zealand, Dunedin Railways operates rail-based excursions along the historic **Tairei Gorge Railway** into Central Otago. The railway itself is an impressive feat of engineering with many viaducts and tunnels along the route. It was built during the 1890s to open land up for agriculture [3].

Also in Otago, two walks and accompanying brochures were developed by the IPENZ (now Engineering New Zealand) Otago/Southland Engineering Heritage Chapter with assistance from Otago Settlers Museum (Toitū) and Dunedin City Council Community and Recreation Services. **Walk 1: The Octagon Route**, and **Walk 2: The Exchange Route** provide maps, photos and short stories about a variety of urban engineering heritage features in a form that is easy for the public to access and enjoy [4].

In Central Otago, the highly successful **Otago Central Rail Trail** is supported by a website (**https://www.otagocentralrailtrail.co.nz/**) and guidebook complete with cycle trail maps and gradient cross-sections, and points of interest [8]. The trail follows 152 kilometres of old rail corridor, and includes many of the original heritage bridges and gold rush sites from the late 1800s.

In New Zealand's North Island, the author recently published **Take Me With You!: A Self-Drive Guide to Whanganui's Engineering Heritage,** which won an Outstanding Contribution to Heritage Award at the inaugural Whanganui Heritage Awards in 2020. It contains forty profiles about engineering heritage features. A sister publication about Otago's engineering heritage is due for publication in the coming months [15].



[Figure 15] Take Me With You!: A Self-Drive Guide to Whanganui's Engineering Heritage

The book **Auckland Architecture Walking Guide: Fifty Buildings Six Routes** by John Walsh and Patrick Reynolds, published in 2019, provides a photo and short essay for each location of interest. There are also maps, an index, and a glossary of architectural terms [13].

In Australia, the **Golden Pipeline in Western Australia** is a heritage trail between the Perth Hills and the Eastern Goldfields along the route of the goldfields water supply scheme designed by engineer Charles Yelverton O'Connor (1843-1902). A heritage trail map, stories and images are shared on an interactive website. The trail can be visited by independent travellers or with a guided tour [7].

Also in the Perth Hills, the **Railway Reserves Heritage Trail** follows the 41-kilometre loop route of the old Eastern Railway. A brochure with map, distances and elevation charts provides information for walkers and cyclists [11].

A self-guided walking tour of **Adelaide's engineering heritage** was developed, complete with informative brochure available online and in hard copy, was created by the SA Division of Engineers Australia in 2010 for Engineers Australia's 90th anniversary. The brochure includes ten themed, self-guide tours including Light & Power and Roads & Rails [11].

On the **North Pennine Ring** in Britain, and on most other canal routes throughout the United Kingdom, **Pearson's Canal Companion** publications have been a practical and informative guidebook series for users of the British waterways network for around forty years. The books are lightweight and portable, and include practical maps for navigation, service points along the canals, locations of interest, and a variety of relevant heritage information [9, 10].

Applications and Learnings

The North Pennine Ring experience illustrates that engaging with and informing visitors about engineering heritage depends on the specific needs, features and constraints of each feature and location. Ideally, approaches will be sympathetically tailored to each site or trail, anticipated audience, and local environment.

[Figure 16] Salterhebble Guillotine Lock, Calder and Hebble Navigation

Other learnings from Britain's historic canals:

- Active, hands-on engineering heritage is ideal. Technical heritage is most engaging when it has a practical, useful purpose and can be touched, activated, and used (e.g. locks, lock mechanisms, bridges and tunnels).
- Places work well when they are attractive for school groups to visit and watch heritage in action e.g. Bingley Five Rise Lock Staircase.
- Stopping spots. These are special points of interest that attract or compel people (ideally both locals and visitors) to stop for a while. This in turn provides opportunities for people to meet and interact, ideally with a heritage feature (perhaps even in operation) as the point of connection.
- Pace. Slowing the speed of travel enables people to connect and converse as they move. It also provides more incentive to stop when a feature or person of interest appears in the landscape.
- Accessibility for locals and visitors – e.g. the towpaths which are functional for narrowboaters and which also serve as a recreational outdoor greenspace for locals.
- Engineering heritage often has a traditional connection to the 'working class'. As the Bridgewater Way initiative demonstrates, heritage revitalisation initiatives ideally include access for socio-economically deprived communities.
- Loops. Circuits provide an attractive way to visit sites of interest without having to repeat the same journey to return to the starting point. This is valid both for the canals themselves – a ring is very attractive, and also for loops where towpaths or other paths (e.g. through an adjacent village) are accessible as a loop through the use of bridges over the canal in at least two locations in relatively close proximity.

[Figure 17] Copley Railway Viaduct, Calder and Hebble Navigation

- Public transport. An attractive value-add feature on the canals is the ability to walk along a towpath through the countryside between two towns and to take a train home for the return journey. Local walkers can enjoy a meal and/or an overnight stay as part of a towpath outing.

- Galleries and museums. These are a regular feature along the North Pennine Ring – including at Wakefield (The Hepworth), Leeds (Leeds Art Gallery, Thwaites Watermill Museum, Leeds Industrial Museum at Armley Mills, Royal Armouries Museum), Skipton (Skipton Castle and numerous small art galleries), Brighouse (Smith Art Gallery). They provide points of interest for visitors and locals, a way to better understand the history of canals and adjacent heritage infrastructure and towns, and places to connect.
- Pubs. As for galleries and museums. Both visitors and locals (and their dogs) need and want to eat!

[Figure 18] Bar view at Granary Wharf, Leeds

- Accommodation. Narrowboaters need regular access to safe moorings, provisions, water, fuel and waste disposal facilities. This is another opportunity for social interaction and to understand an area's stories and heritage.
- Resilience. The ideal networks are not just tourist trails – they are enjoyed by locals, who keep them maintained, safe and functional during the off-season.

CONCLUSIONS

Britain's North Pennine Ring canal network is an outstanding engineering achievement. It crosses the Pennine Hills to connect Leeds, Manchester and ports on both coasts, and was built to serve cotton milling and wool processing industries during the Industrial Revolution (c. 1760-1840). Some Ring waterways have remained navigable throughout their lifetime, but many became derelict and were closed. Renewed interest in canals from the 1980s saw the North Pennine Ring reopen as a complete navigable loop in 2002.

Locks and lock mechanisms, towpaths, swing bridges and tunnels are some of the many engineering heritage features that make canals interesting places to visit and explore for narrowboaters, pedestrians and cyclists, and for both visitors and locals. Canals also provide important greenspaces for socioeconomically deprived communities, habitat for wildlife, and places where people can pause and connect with one another.

Locks and other engineering heritage features create special places to learn and connect, while the pace of travel along waterways is conducive to 'travelling conversations' between narrowboaters and towpath users.

The North Pennine Ring experience offers useful applications for Australasian engineering heritage initiatives. Most importantly, each heritage feature and trail works well when solutions are tailored and align with a specific location and character – a one-size-fits-all approach is unlikely to achieve best results.

Other findings from the canals experience include incorporating active, hands on opportunities where possible – including for school visits, providing stopping spots for people to connect and enjoy a feature and the company of others, a slower pace improves interaction and interest, access for both visitors and locals (including in more deprived regions) helps build resilience and improve wellbeing outcomes, loop trails provide added interest, and integration with public transport/galleries/museums/pubs and cafes/accommodation providers helps to optimise the canal experience for everyone.

ACKNOWLEDGMENTS

Thanks to my husband Allan Wrigglesworth for help with research and preparation of this paper.

All photography and the map are by the author.

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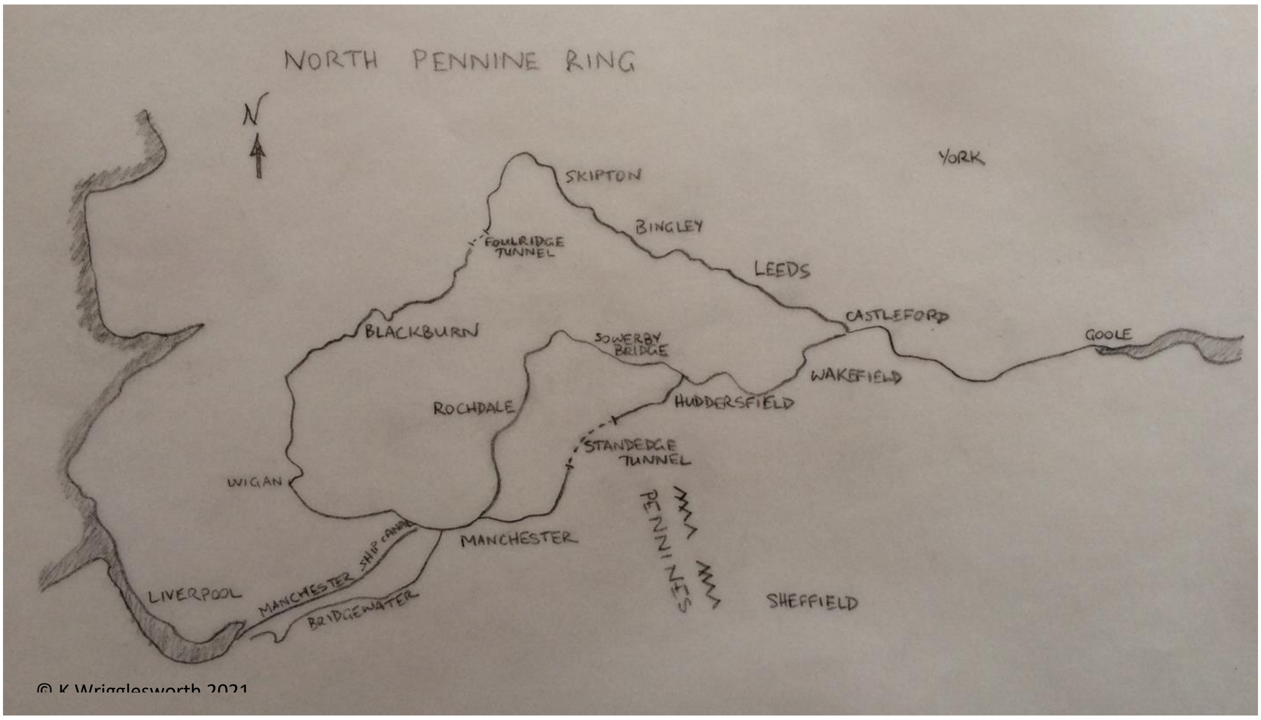
APPENDICES

Appendix A – North Pennine Ring location map



HOORAY FOR THE A TO JS

Rob Aspden, Dist F EngNZ, BE (NZ), D Phil (Oxon), Past President of IPENZ

Summary: The 'A to Js' (aka Appendices to the Journals of the House of Representatives) are an amazing storehouse of engineering heritage information relating to New Zealand government engineering projects. Most of Rob's use has been with the D-1 appendices of the Public Works Department. But government engineering information is found in a number of appendices. In the 1936 A to Js there were 16 appendices with engineering connections, including Public Works (which included a Hydro-electric Branch), Railways, Post & Telegraph, a Broadcasting Board and Department of Scientific and Industrial Research (DSIR).

INTRODUCTION

I need to start by explaining what the 'A to Js' are in New Zealand, and why I think that they are so valuable as an engineering heritage resource. The A to Js are more properly known as the Appendices to the Journals of the House of Representatives (aka AJHR). They are the annual reports of each Government department. This of course includes several departments which have engineering involvement in the country's development. They are important for engineering heritage research because they provide an available, detailed record of the country's engineering works which have been undertaken by the Government. Thankfully you can go to Google and search for 'A to Js, On-line'. Up will come an on-line list of the AJHRs digitised up to 1950. As digital copies they start in 1854 with what are described as 'VP's (Votes and Proceedings of the House of Representatives). They changed to AJHRs in 1858 and continue to be accessible on-line until 1950. After that they are only found as printed bound copies in the major libraries. Of course, there are many other records, mainly held by Archives New Zealand, but some have not survived the passage of time, as I will later relate.

I further need to clarify my terminology for this paper. I am going to distinguish between 'AJHR' and "A to Js". In this paper, the printed reports are "AJHR" and where available, cover the period from 1854 to the present. The reports after the late 1980s are of less engineering heritage significance because of changes made by the Government to introduce more competitiveness in engineering work. I make no comment on whether I think that this has worked in the best interest of the country.

When I use the term 'A to Js' I am talking about those AJHR available online and are for the period 1854 to 1950. How I used the AJHRs then relates mainly to my own personal circumstances. For a quick preview, here is the link: **https://atojs.natlib.govt.nz/cgi-bin/atojs?a=p&p=browsebyvolume**

WORK FOR THE WORKS DEPARTMENT

Since I am talking about reports from all Government Departments, but because I am mainly using examples from the Government Works Department, I need to explain the various names of that department. When I talk about the Works Department, I am referring to not only the PWD (Public Works Department – 1870 to 1946), but also to the MOW (Ministry of Works - 1943 to 1973), the MWD (Ministry of Works & Development – 1973 to 1988), and the Works and Development Services Corporation (a State-Owned Enterprise – 1988 to 1993). After that it was sold off and became various privately owned firms. More details are provided by Jim Muir in his recently produced book, *Opus Works* [1].

Apart from PWD, I worked for each of the above from my first holiday work with the MOW when I was still at school (1954 and 1955), then briefly after I graduated from Auckland University with a BE for a short period in 1960, before heading off overseas for further study. Back in NZ in 1964, I worked with the MOW in Auckland, Whangarei and Wellington before being sent overseas for attachment with the UK Atomic Energy Authority in 1967 when NZ was planning to enter the nuclear age. When that was postponed indefinitely, I returned to be involved with the construction of the New Plymouth Power Station before moving to Power Division design office in MWD Head Office. I spent the rest of my time with Works there for the rest of my career until I retired in 1997.

The transfer of the Works Department into a privately owned organisations went quite smoothly and the staff coped well with the change. However, I am not so sure that the country has benefitted from the loss of good engineering advice available to the politicians, with a motive change from 'service' to 'profit'. I just think back to a remark made by broadcaster Hugo Manson when he and Judith Fyfe completed the Electricity Centenary Oral History programme in 1988. He said, the tapings proved quite unlike any other archive project they had done.

> We were struck by the absolute commitment of the people to their job. There was almost an element of adventure and romance - they spoke of a power station as sailors might refer to their ship [2].

In my years with Works I regularly saw that sense of service and mission. I don't think that Treasury or the politicians understood that (with some notable exceptions).

ENGINEERING DEVELOPMENT IN NEW ZEALAND

Early engineering development was done by the provinces in a way and to a standard that suited them. This was arranged with the limits of the local economy and little thought appeared to be given to developing to a national standard. As an example, *'An Encyclopaedia of New Zealand'* recorded that;

> Early railway lines were built to three different gauges (Canterbury 5 ft 3 in (1600 mm), Southland 4 ft 8½ in (1435 mm), Otago 3 ft 6 in (1067 mm)), but the Public Works Act of 1870 the Central Government fortunately asserted its powers and standardised the gauge for the whole country at 3 ft 6 in [3].

The provincial approach started to reduce in 1865 when the capital of the country was moved from Auckland to the more central Wellington.

Then Furkert, in his book 'Early New Zealand Engineers', described it as the start of 'The Great Public Works Era' when he wrote:

> In 1869, when Vogel, later Sir Julius Vogel, realising that the Provincial system, under which a number of centres endeavoured to develop their surrounding areas to the benefit of those centres and without due regard to the interests of New Zealand as a whole, had outlived its usefulness, proposed the development of a system of communications which would knit the whole together [4].

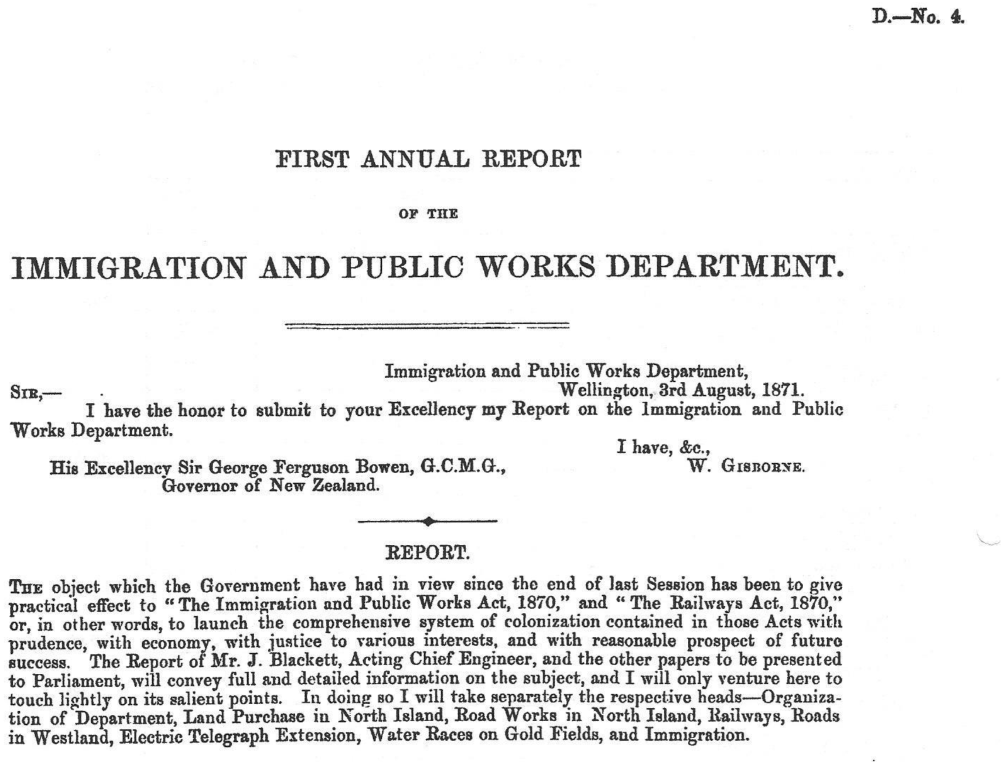
And, this most important milestone was further described by Rosslyn Noonan in her book, *By Design: a brief history of the Public Works Department, Ministry of Works, 1870-1970*.

> On 28 June 1870 the Colonial Treasurer, Julius Vogel, delivered his Financial Statement to the House. The basic theme was the urgent need to promote settlement in New Zealand. He proposed to open up the country with extensive public works, particularly roads and railways, and to attract settlers by assisting immigration. To finance his scheme, he advocated borrowing overseas £10 million ($20 million) over a period of 10 years. Nowhere in the address did Vogel suggest how such a scheme would be supervised. This lack of concern for administrative detail was to create many problems in the execution of the public works programme.
>
> In Parliament immediate reactions to Vogel's proposals varied from incredulity to enthusiasm – and were frequently a combination of both. R. G. Wood, Member for Parnell, had "never heard of a scheme so wild, so unpractical, and so impracticable."
>
> The majority, however, saw Vogel's plan as a panacea. A colony-wide communications system "would strongly tend to unity of sentiment, and render possible something like patriotism in the country." It would create a nation where previously there had been only a collection of provinces [5].

It was one of the most important events in the development of the country, and resulted in major infrastructure developments and the benefit of a centralised control. While initially there was no clear plan for the administration of the planned public works. Noonan noted that to

> …remedy the situation, Hon William Fitzherbert suggested that a distinctive department be set up and that a Minister for Public Works and Immigration be appointed. In its final form that is just what the Immigration and Public Works Act 1870 provided for [6].

So, in 1870 the Public Works Department was formed, and Hon William Gisborne was appointed the interim Minister of Immigration and Public Works. In the 1871 PWD statement he reported (Part of the first pages below):



D.—No. 4.

FIRST ANNUAL REPORT

OF THE

IMMIGRATION AND PUBLIC WORKS DEPARTMENT.

Immigration and Public Works Department,
Wellington, 3rd August, 1871.

SIR,—

I have the honor to submit to your Excellency my Report on the Immigration and Public Works Department.

I have, &c.,
W. GISBORNE.

His Excellency Sir George Ferguson Bowen, G.C.M.G.,
Governor of New Zealand.

REPORT.

THE object which the Government have had in view since the end of last Session has been to give practical effect to "The Immigration and Public Works Act, 1870," and "The Railways Act, 1870," or, in other words, to launch the comprehensive system of colonization contained in those Acts with prudence, with economy, with justice to various interests, and with reasonable prospect of future success. The Report of Mr. J. Blackett, Acting Chief Engineer, and the other papers to be presented to Parliament, will convey full and detailed information on the subject, and I will only venture here to touch lightly on its salient points. In doing so I will take separately the respective heads—Organization of Department, Land Purchase in North Island, Road Works in North Island, Railways, Roads in Westland, Electric Telegraph Extension, Water Races on Gold Fields, and Immigration.

[Figure 1]

> The object which the Government have had in view since the end of last Session has been to give practical effect to "The Immigration and Public Works Act, 1870," and "The Railways Act, 1870," or, in other words, to launch the comprehensive system of colonization contained in those Acts with prudence, with economy, with justice to various interests, and with reasonable prospect of future success. The Report of Mr. J. Blackett, Acting Chief Engineer, and the other papers to be presented to Parliament, will convey full and detailed information on the subject, and I will only venture here to touch lightly on its salient points. In doing so I will take separately the respective heads — Organization of Department, Land Purchase in North Island, Road Works in North Island, Railways, Roads in Westland, Electric Telegraph Extension, Water Races on Gold Fields, and Immigration [7].

So it was that Te Ara (NZ Encyclopedia) noted that 1870, Vogel's plan saw:

> …the launch of 'the most ambitious development programme in New Zealand's history.…The money (loan of £10 million) was used to assist British migrants, speed up the purchase of Maori land, and build the public works or infrastructure essential for economic development: railways, roads, bridges, port facilities and telegraph lines [8].

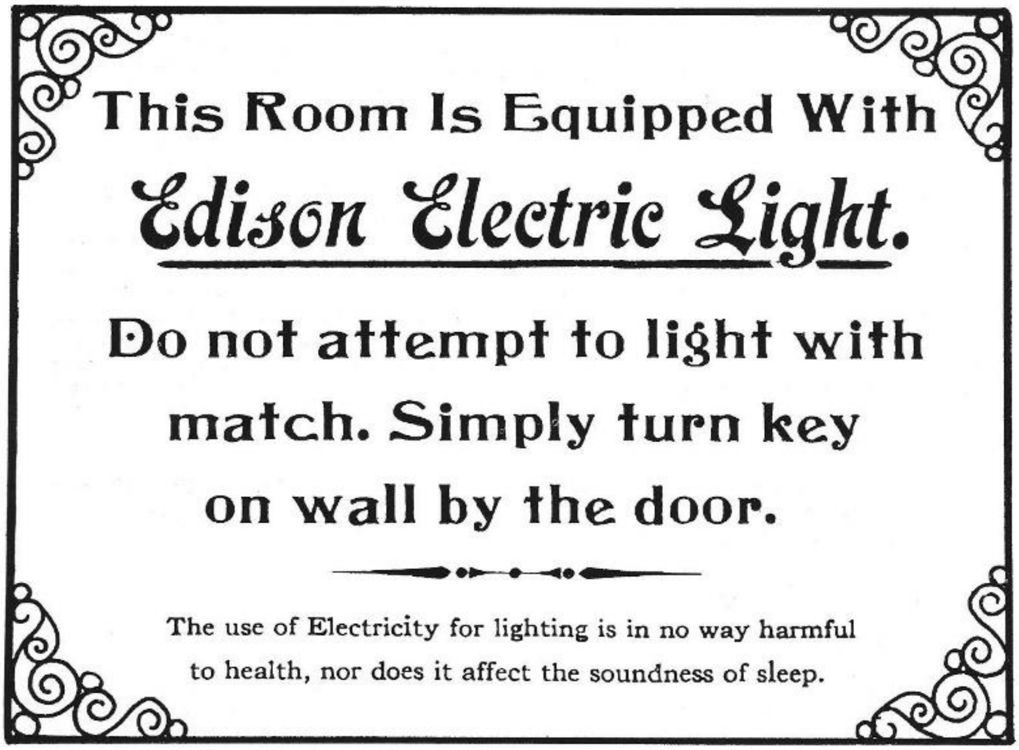
Te Ara then reported that in the following decade:

> New Zealand's rail network grew from a mere 74 km in 1870 to 2000 km by 1880. New regions were opened up to Pakeha settlement, and central government became increasingly powerful, eclipsing its provincial rivals [8].

The provinces were eventually abolished in the Provinces Act in November 1876 [9].

Progress slowed in the following few years as a mini depression occurred until a new Liberal party government under John Ballance as Premiere was elected in 1891. Richard Seddon was given a ministerial position in the government and then became Premier after Ballance's death in 1893.

And in a new development, during the last two decades of the 19th century there was a growing interest in electricity. This is described in my paper entitled *'Origins- The progression from curiosity to amenity'* which described significant events in the growth of the use of electricity in the period from 1880 until 1911.



[Figure 2]

It was yet another key story of the involvement of the New Zealand government in engineering works.

> In the early years the government played nothing more than a watching role, apart from the less than enthusiastic installation of lighting into the Parliament Building and the more successful lighting of the Government Printer's Office. The main interest in electricity lay with the Telegraph Department and the impact that any electric power lines might have on the telegraph system.
>
> At the same time, the use of water was mainly of importance in relation to mining and was therefore controlled in the mining districts by the Mines Act 1877. This meant that all water of streams, lakes and rivers was now under the direct control of Crown agencies [10].

Around the turn of the century people were learning about the usefulness of electricity. There were a number of local entrepreneurs (including J C Firth), local bodies, private consultants such as Mr Allo, a Swiss consultant who set up an office, [11] and overseas firms (such as the Gulcher Electric Light Co) who wanted to have a bit of the action. The consultants pressed their case, many focussing on the Huka Falls. However, private concerns who wished to generate electricity to supply the public were still bound by the Electric Lines Act 1884, and needed a special act of Parliament.

Accordingly, under this pressure, the Premier, the Hon. Mr. R.J. Seddon introduced the Electrical Motive-Power Bill which now required the consent of the government before any local body could grant the right to any concern to generate electricity for electromotive power. This was a significant step in greater involvement by the Government. Further this Act as passed in October 1896 also included a clause which required the government to report on “the feasibility of utilising the water- ways of the colony for the purpose of supplying electrical motive-power for use on the goldfields” [12]. Staff of the Public Works Department were set to work gathering information about rivers, lakes and streams around the country.

[Figure 3] Star (Christchurch), 25 October 1887.

So, in 1903, an overseas expert, Mr. L.M. Hancock from the Bay Counties scheme in San Francisco was invited to visit New Zealand to report on the hydro-electric resources available in the colony. Mr. P.S. Hay, Superintending engineer of the PWD accompanied Mr. Hancock for his 82-day visit to New Zealand, and Hay obviously learned a great deal from his time spent on the tour. Consequently, when Hancock's report proved less than adequate in providing the specific information that the politicians required, Hay was asked to produce a second report. An account of these events is provided in the paper ‘Mr Hay – please report’ [13]. More reference is provided to these two reports later as examples of the value of the A to Js.

So further involvement of the Government in engineering was established. This was reinforced by the introduction of the Water Power Bill to the house in September 1903. This bill provided for the “vesting in the Crown of waters for electrical purposes and for the utilising of such waters for those purposes.”

At this stage and with the growing prosperity in the country, the public no longer saw electricity as a plaything but as a basic amenity. They were starting to demand more ready access to electricity supply. The era of major electricity development was now launched in New Zealand.

And with it, the grip that central government had on major engineering work which was to continue to the benefit of the whole country for the next 80 years.

INTEREST IN ENGINEERING HERITAGE

I became interested in New Zealand's electricity industry heritage in the 1980s when its centenary was about to occur. It started with involvement with two projects for the celebration of the centenary of electricity in New Zealand:

Early development in electricity history in New Zealand

This resulted in organising some students to search the country's newspapers for items about the early establishment of electricity in the country, for the period 1880 until 1910. This was on the understanding that until late 1890s the Government departments had little interest in recording the development. This was aimed at providing a record of events in those early years for a book to be published on the generation of electricity in NZ. This book, *People, politics & power stations*, was published in 1991 [14]. The information recorded has been stored in the Alexander Turnbull Library. It was an interesting and laborious effort which since then could have been done much more easily using "Papers-Past". It also resulted in a paper presented to the IPENZ Annual Conference held in 1988 [15]. The information can be accessed as follows:

Electricity Centenary Oral History Project

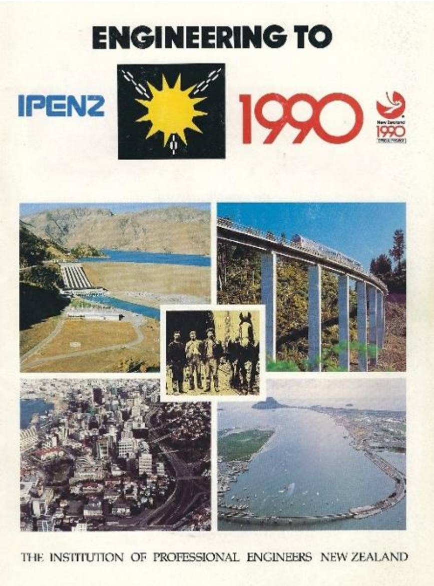
Details of this were given in an article in the MWD staff magazine "Works News", Sep/Oct 1987 which reported:

> Looking back through available information on the early history of electricity provided a mixture that was "more fable than fact", Rob Aspden said. He saw the need to ensure that the record of more recent years should be as factual as possible - by recording the words of the people actually involved in major events and projects.
>
> As its contribution to the electricity centenary, the Ministry of Works has commissioned the Oral History Archives to interview 30 people connected with the development of electricity in New Zealand [16].

Admittedly, this had nothing to do with the use of either AJHRs or A to Js. But it was a worthwhile engineering heritage project! Incidentally a more detailed paper was presented at the Australasian Engineering Heritage conference in Auckland in 2000 [17].

IPENZ 1990 project

I was again involved as chair of the Wellington area organising committee in 1990 when IPENZ celebrated the country's sesquicentennial by marking a number of significant engineering works in New Zealand [18].



[Figure 4]

Wellington Engineering Heritage Chapter

When I retired in 1997, I established an IPENZ engineering heritage committee in Wellington which I chaired for much of the time until moving north in 2012. Since then I have been involved in the Auckland Chapter.

USE OF THE AJHR VOLUMES

When I was in Wellington I had ready access to the National Library, and also to Archives NZ and for a period, the Parliamentary Library. So, I had good access to the large bound volumes of the AJHR reports, and the A to Js (digitised version) did not exist as far as I am aware. Then up north, some 30 km north of the centre of Auckland it was much more difficult to access the printed volumes, but I was delighted to discover the on-line versions.

My first use came when I was asked to write the story of the Aspden family who emigrated to New Zealand in 1865. This part of the Government's plan to encourage immigration to the country. This was what was known as the 'Special Waikato Immigration Scheme'. Although it related to Auckland Province it was part of the NZ Government's plan to stimulate immigration, and (dare I mention it!) to occupy land in South Auckland that had been confiscated from the Maoris. So, the drive for immigration is reported in some detail in the AJHR and became an integral part of the purpose of the PWD [19]. An example is found in AJHR 1864, Appdx D-03.

Returning to the use of the AJHRs for engineering heritage research, it will be obvious that my main interest has related to the supply of electricity in New Zealand. The AJHRs were occasionally used for the "Origins' paper [10] although most information came from the newspaper research in the Parliamentary Library.

The next major use was for the story behind the Hay report, (AJHR 1904, Appx D-1a) but did not include the Hancock report (AJHR 1904, appx D-7). I had not realised its existence and failed to look for it (later found from the A to Js as AJHR 1904, appx D-7). What I did find as I searched in Archives NZ was Head Office PWD Correspondence register for Inward and Outward mail. The search for those letters, so carefully recorded resulted in dismay – they had all gone up in smoke in the Hope Gibbons building fire in 1952 [20].

Refer to: **https://teara.govt.nz/en/photograph/41758/hope-gibbons-fire-1952**

That was a most regrettable event involving a significant loss of the PWD/ MOW records up to that time. And it illustrates the need for appropriate storage of paper material. Fortunately, the AJHRs remain and now of course easily accessible through the A to Js Online.

Use was also made of AJHR for some of the record items I contributed to while involved with the Wellington Engineering heritage chapter. But of course, there was good information readily available in the NZIE and IPENZ 'New Zealand Engineering' journals. Many of these are now available on-line for ready access.

But it has to be admitted that the cumbersomely large volumes of AJHR in the libraries are difficult to use and even more difficult to capture text from. So, the production of the A to Js is a real boon to research and producing articles about early engineering.

USE OF THE A TO JS:

Now, having moved to Auckland, and away from the convenience of ready access to the AJHRs, as I detailed earlier I had to learn to use their on-line versions, the A to Js. This proved of value for my next paper [13] and for various articles written for the Engineering New Zealand engineering heritage website as Record items. The Hay report [21] has long been regarded as the foundation document of the New Zealand hydro-electric system, built by the Government from 1911 to 1993. It had long been an interest of mine, and I had ready access to that report. As mentioned earlier, I did not find the companion report by Hancock until I started using the A to Js. I had already been discouraged by finding that the PWD Head Office correspondence on the subject had been lost in the 1952 Hope Gibbons fire in Wellington.

Only some years later after my move north did I go looking for Hancock's report and found it as a later appendix [22]. Much to my surprise I found that it included a reasonably full description of Hancock's travel with Hay, which on careful analysis I was able to establish that the full journey for Hancock was over 6,000 km from after arrival in Auckland on 5 October 1903 to twelve weeks later when Hancock and family departed by mail steamer from Auckland on 25 December. Aratiatia rapids on the Waikato River (shown here) was one of the sites identified.

[Figure 5]

There was no mention in the text that Hancock's wife and child accompanied him on apparently the full journey. The only evidence for this was their names included in each passenger list for each of the ships/ ferries they travelled. I suspect that Mrs Hancock was there as more than a tourist, but acted as secretary for her husband. Very valuable considering the amount of detail he collected.

[Figure 6]

The map of their South Island (above), shows their extensive travels (Over 4000 km).

The description of the journey gives much detail of the difficulties they encountered, an added bonus for the record that he provided. The weather was not always kind to them, and they struggled at times. But I was specially struck by one day in the Waitaki valley when Hancock becomes quite lyrical in telling of his experience:

> **November 6** (1903): Started out early on horseback and rode across the Ohau River bridge down the west side of the river to its junction with the Waitaki, and thence along the Waitaki to the Goose Neck. The last half-mile the hills were so steep that we left our horses with a rabbiter, whom

we had impressed as a guide, and proceeded on foot to the top of the ridge, where we got an excellent view of the river for a long distance farther. It was growing late, so we hastened to retrace our steps, stopping long enough to drink a "billy o' tea," which some workmen along the road had promised us, and never was tea more welcome. We had hardly travelled over thirty miles, and had twenty more to go before we could get our dinners. As the sun was setting that evening, we had a rare view of Mount Cook. Never shall I forget it. We were in the shadow of the clouds; a rift, however, let through a flood of light upon the distant majestic mountain, snow-covered, illuminating it, while all the other peaks were in shadow. Then in the next half-hour there were variations of light and shadow which were beyond man to describe. The time, the surroundings, the distance, our isolation —all affected us, and, though at first we expressed our wonder by exclamation, as the magnificence of it grew on us we became silent, gazing with admiration inexpressible [23].

[Figure 7]

Lake Pukaki and Mount Cook shown above

I hoped that I might find a report of the Hancock's experience of their tour of this wild country in one of the San Francisco newspapers but disappointingly have so far have failed to find that.

Of course, as indicated in my 'Hay' paper I was able to use the PWD reports that came out each year to follow the progress with the Government's role in building and supplying electricity to the country. It was rather slow to start with, mainly because of the emphasis on the railway construction – particularly the North Island Main Trunk (NIMT) railway. There is an amusing story about the interest of the politicians in the completion of the connection to Auckland. Not of course, recorded in the 'A to Js'! The PWD statements continued to provide detailed information on the progress of the construction of railway lines around the country and the establishment of the Hydro-electric Branch in the PWD and the start of the Government power station in the country.

They were well used for a description of the development of the rail system in Northland which I produced for a record item in the Engineering NZ website. Refer to this url:
https://www.engineeringnz.org/programmes/heritage/heritage-records/northland-railways/

[Figure 8]

A quick look at this record item will show the spasmodic development of the rail line and from other sources I also learnt of a Commission established in 1911 to recommend the continued development of the railway in Northland. I managed to locate the report of this commission which appeared as AJHR 1911 Appx D-04 'Northland Railway – Report of the Commission. Which recommended a line straight up the centre of Northland to Kaikohe. This is shown in the above (Northland Railway) paper in the map for 1914.

The Commission had received 69 submissions, many of them from local farmers keen to get a rail line running near to their rather isolated land. The Government applauded their recommendation, and then proceeded to complete the connection to Whangarei in 1926, but proceeded to slowly continue the extension of the line along the first part of 1911 recommended route until 1928. Then came the 1929 depression followed later by the Second World War. However, it was later noted that Thornton shows a picture of the Mangatipa viaduct suggesting it was for the proposed rail line to Kaikohe [24].

This caused more investigation to check if this had indeed been the case. Researching PWD statements in 1928 and 1929 (AJHR 1928 and 1929, Appx D-01) appears to disprove the suggestion, but it was an interesting comment on the enthusiasm of the PWD for thinking ahead. They were not to know at that time for what lay ahead!

Another Northland project for which I produced an Engineering NZ website report was the Wairua Falls power station. This was not a government project but appears from time to time in PWD statements.

Particularly in Hancock's and Hay's reports in 1903 when the site was visited. Its output appears in later A to Js and AJHRs. The State Hydro-electric Department (SHD) grew out of the PWD Hydro-electric Branch in 1946 and produced its own AJHR Appendix D-04 from then on. So, they too are available for six years as A to Js. After that year to use the information, I now have to resort to AJHRs with limited access – more papers I would like to write. Particularly how the power planning worked during the 1950s power blackouts.

THE FUTURE (OR IN MODERN PARLANCE, "MOVING FORWARD")

Yes, it has been a privilege to have ready access to the A to Js containing such information packed reports. As indicated, I have also used them for family history research and for research into the lives of some of the local WW1 servicemen. It is all part of a move to increasingly digitise documents to improve access for researchers. There are other examples of this process such as the Electronic Text Collection at Victoria University of Wellington, the service records of WW1 servicemen and other records at Archives NZ, and facilities such as Wikipedia. I have added an appendix (yes, it's that word again!) to list some of the techniques I have used to find my way around them and to extract the information. (Refer to Appendix 1 – Using the A to Js)

As already emphasised, I see the A to Js as part of our heritage, not just engineering heritage. I have already talked about the danger of fire for archival records and gave as an instance the 1952 Hope Gibbons fire. It is hard to get away from the threat of fire when one views reports of wildfires around the world. But do we also have a threat to digital information from those who seem intent of invading and damaging the world-wide network of digital information for their own personal gain?

But I think that for New Zealand people, and of course, researchers from other countries, interested in engineering heritage they provide a valuable and accessible resource.

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[20] Strachan, Stuart. “Archives - Government archives,” Te Ara - the Encyclopedia of New Zealand, http://www.TeAra.govt.nz/en/photograph/41758/hope-gibbons-fire-1952

[21] AJHR 1904; Appx D-1a – “The Hay report”

[22] AJHR 1904; Appendix D-07; “The Hancock report”

[23] AJHR 1904; Appx D-07; “The Hancock report” – 6 Nov 1903

[24] Thornton, Geoffrey. *Bridging the gap: early bridges in New Zealand 1830-1939*. Auckland: Reed, 2001, p168.

APPENDIX 1: MY COMMENTS ON THE USE OF THE A TO JS

The naming of the A to Js generally follows a largely logical pattern, although is likely to change when the Department name or responsibility changes. As an example, here are some relevant appendices with engineering involvement for AJHR 1904:

C-01 Lands & Survey Dept

C-02 Mines Statement

C-03 The goldfields of NZ (etc)

C-12 NZ State Forests

D-01 Public Works Dept (PWD) Statement

D-01a NZ Water Power (Hay Report)

D-02 Railway's statement

D-04 Wanganui River improvements

D-06 Completed railways handed over (to Railways Dept)

D-07 NZ Water-powers (Hancock report)

E-08 Education – Canterbury College

F-01 Post & Telegraph Dept

F-07 Durability of NZ timbers

F-08 Telegraph cables.

The content of each departmental appendix (report) generally followed the same sort of order. First came the departmental minister's statement, which provided a good overall summary of the department's activities. Because I have used AJHR 1904 Appendix D-01 (PWD statement) above, I give sizes relating to that as an example of size. They differ of course as a researcher will find:

AJHR 1904: Appx D-01

Minister's report	13 pages
Expenditure and progress tables	51 pages
Appx D: PWD Engineer-in-Chief	14 pages
Appx E: Supplement on Midland Rlwy	121 pages

I have also checked the size of two smaller reports in AJHR 1904:

Appendix D-01a (Hay Report) is 28 pages long, with an additional 40 pages of maps

Appendix D-07 (Hancock report) is 15 pages long.

The layout is a bit complicated and I have had to simplify it to show major sections of information for someone searching for engineering heritage details. There is however no better way to understand than to checking in yourselves. That's the easy part!

And, I mean that – start with one of the D-01 appendices. First, when you search for the "A to Js – online" use your search engine to choose the appropriate volume in the list, then 'narrow your search' and go to the selected appendix. That will bring up the whole appendix with the first 50 pages per screen. So, in the case of the appendix listed above, the (1904, D-01) is on three screen pages. Of the other two listed above, (1904, D-01a, 79 pages) is on two screens and (1904, D-07, 15 pages) is on one.

USE OF ALL OR PARTS OF THE APPENDIX

It should be noted that the AJHR have themselves got appendices, as will be noted in the following example. The example uses material from 1919 AJHR, Appendix D-01. This appendix has four appendices:

Appendix A: PWD Expenditure for the year 1918 – 1919

Appendix B: PWD Annual report by the Engineer-in-Chief

Appendix C: Annual report on public buildings by the Government Architect

Appendix D: Annual report Electrical & water power schemes by Ch Electrical Engr

I have used part of Appendix D to illustrate use of the A to Js.

At the top of each screen for any appendix you will see that you can have either ‘**download a printable pdf**’ file (the size is shown), or ‘**view computer generated text’**.

The first is useful of you want reasonable quality print out to use for display or an illustration in your paper. It is easier said than done because when you decide you will have difficulty finding the item you want. The page numbers for item are unlikely to be the same you have to enter in the print dialog box. It is different for each situation, so you will just have to try hit and miss trials.

As an example, I decided to use one of the examples I used in my paper ’Mr Hay – please report’ (Aspden 2017), to demonstrate the problem. Here is the first page of the Chief Electrical Engineer from AJHR 1919; Appendix D-01, appendix D, p 42 from the main file. (See Fig. 1). Readable, but not very clear.

Figure 2 shows part of a download of a clip from page 42 of the computer generated text. This shows the problem of including tables. Using this digitised process is fine if you carefully select the text you want to clip and I recommend avoiding tables. There is also the problem of locating the page. I eventually found it by trial and error as page 56.

Figure 3 shows the same page 42 taken from the printable pdf. This was then scanned to produce a jpg file from which the first table on page 42 has been taken (Fig 4). I suggest inserting this into a word file with the remainder of the text.

Figure 5 shows the clip I produced after some effort massaging the table text from figure 2.

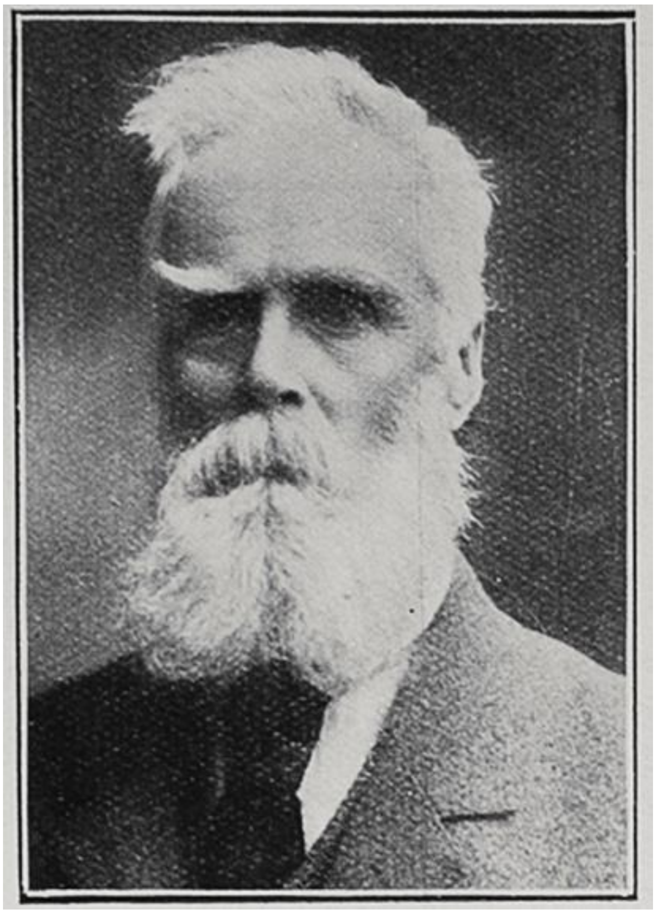
Can be a bit of a struggle, but I am still learning. I recommend the effort!

TECHNOLOGY PREDICTIONS BY JAMES STEWART 120 YEARS AGO, AND WHAT HAVE WE GOT IN 2020?

John La Roche, Engineering Heritage Auckland Chapter

JAMES STEWART

I have always had great admiration for the early engineers who came to New Zealand in the 1860s and later when there was very little infrastructure and very little money for development. These engineers were able to turn their skills to almost any technical task, civil, mechanical or electrical. James Stewart was one of those.



[Figure 1] James Stewart

James Stewart was President of the Royal Society of New Zealand in June 1901 when his Presidential address described the advances in engineering over the previous 50 years and his predictions for future developments. This paper compares James Stewart's predictions with present day engineering.

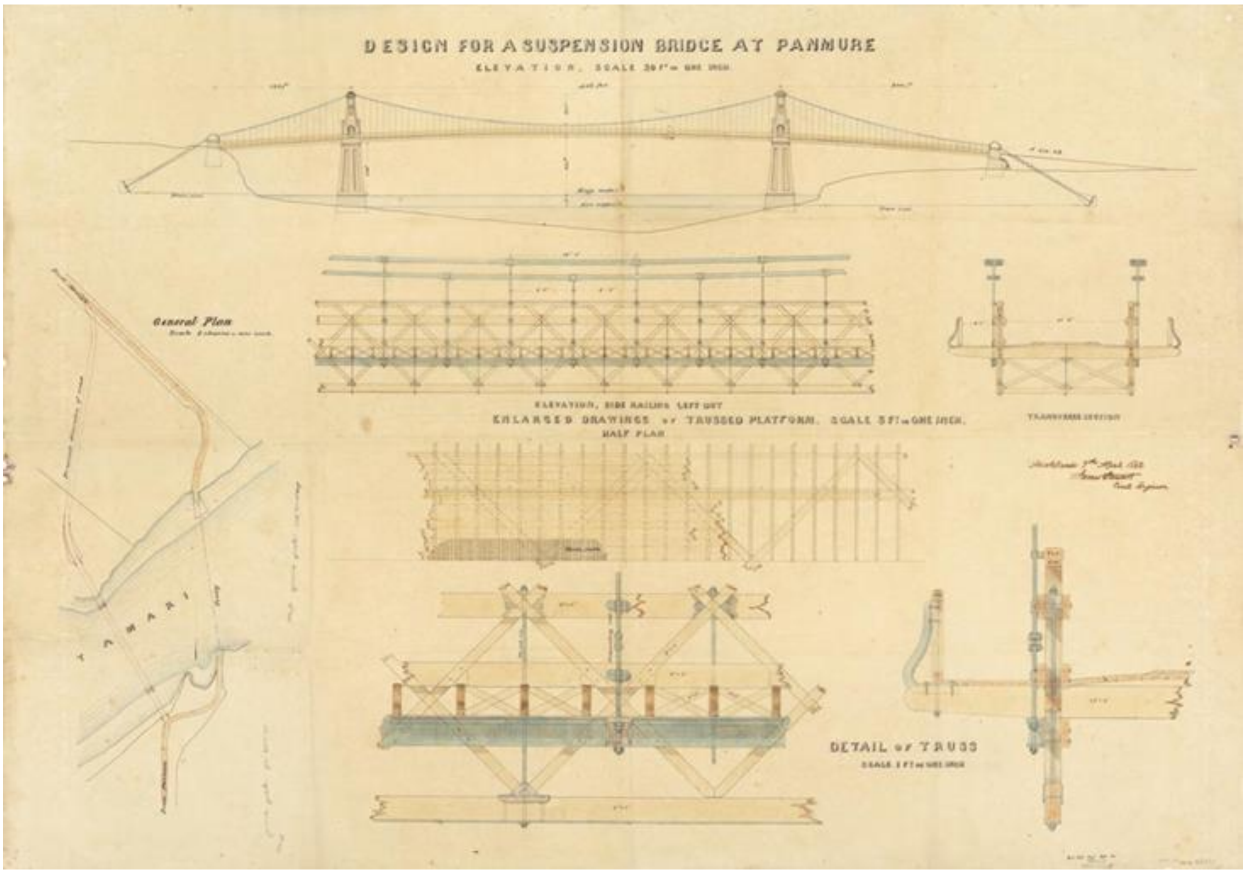
Anne Stewart Ball, James Stewart's great granddaughter who lives in Tairua, Coromandel, has provided biographical information about James Stewart.

James was born in Scotland and educated at the Perth Academy. As was the traditional method to become a professional engineer at the time, he was articled to Peter D Brown M.I.C.E. at the age of 18. Under Brown, Stewart was engaged in roads, bridges, railways and waterworks.

Stewart came to Auckland in 1859 where he set up practice in Shortland Street as a Civil Engineer and Surveyor. One of his first assignments was to enter a design competition for a desperately needed water supply for Auckland. He won the competition prize of £50 with his design to pump one million gallons per day water from the Onehunga Springs, but it did not proceed. With Samuel Harding he was engaged in surveying the Auckland Railway to Drury before being appointed Engineer to the Auckland Board of Works in 1862.

At the Board of Works he became responsible for the design and supervision of the main sewer down Queen Street replacing part of the Ligar storm water Canal. The formation and maintenance of roading within Auckland City was also his responsibility, but the Board had very little money and had to rely on inadequate grants from the Provincial Government. There was no money to pay his salary at one stage.

[Figure 2] James Stewart's design for Queen Street Sewer 1862. Auckland Council Archives ACC 015 678-001



[Figure 3] Stewart's unsuccessful design for the Tamaki River Bridge at Panmure. Sir George Grey Special Collections NZ Map 5552i

With the Waikato Māori wars erupting in 1863, Stewart was sent to Sydney to supervise construction of the steamers Koheroa and Rangariri for military service on the Waikato River. Later they were fitted with bullet proof gun turrets, one of which remains at Mercer as a memorial to soldiers killed in WW1.

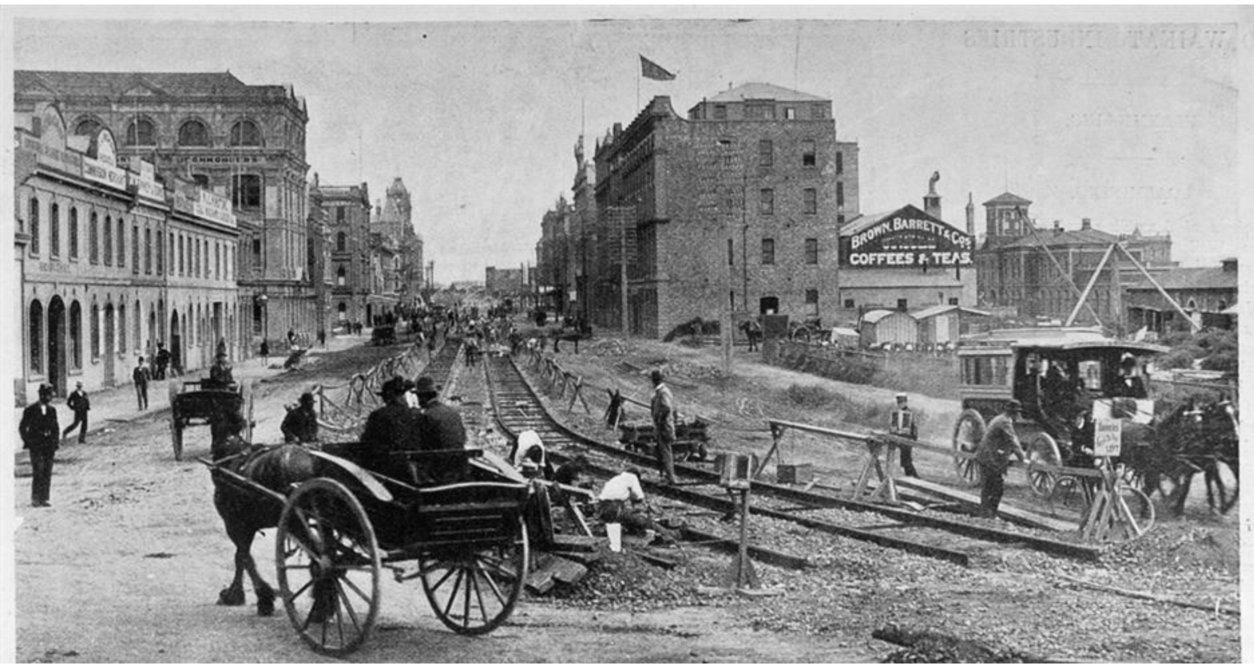
James Stewart and Samuel Harding were appointed engineers for the Auckland to Drury Railway when construction commenced in 1864 but by 1867 the available funds were exhausted and all work stopped.

In February 1867 Stewart was appointed Inspector of Steamers. He completed designs and supervised construction of lighthouses at Bean Rock, Ponui Passage and Manukau Heads after initial designs had been started by James Balfour who drowned before the designs were completed.

With the Vogel policy of promoting immigration, roads and railway construction, Stewart was appointed to survey and up-grade of the Auckland to Drury railway. In 1872 he became the Resident Engineer for the construction on the extension to Mercer. In 1874 he was placed in charge of all railway works in the Auckland Province including the railway to Te Awamutu and the line from Auckland to Kaipara. He also became responsible for all road works north of Auckland, but by 1877 along with 175 other Public Works staff he was retrenched.

In partnership with Ashley Hunter in 1892, Stewart established a wide and varied consulting practice, being appointed engineer to the company building the Rotorua Railway, the Thames Valley railway and Te Aroha County tramways. After visiting England in 1896 where he studied electric trams, he was appointed consulting engineer for laying of Auckland tram tracks.

Stewart was elected an Associate Member of the UK Institution of Civil Engineers in 1868 and Member in 1877. He became a licensed surveyor in 1881. He was President of Royal Society in 1890 and 1901. He died in Auckland aged 82 on 12 February 1914.



[Figure 4] Laying tram tracks in Custom Street Auckland November 1901. Sir George Grey Special Collections AWNS-19011107-5-1

STEWART'S 1901 ADDRESS TO THE ROYAL SOCIETY

Wireless messages

Stewart postulated that

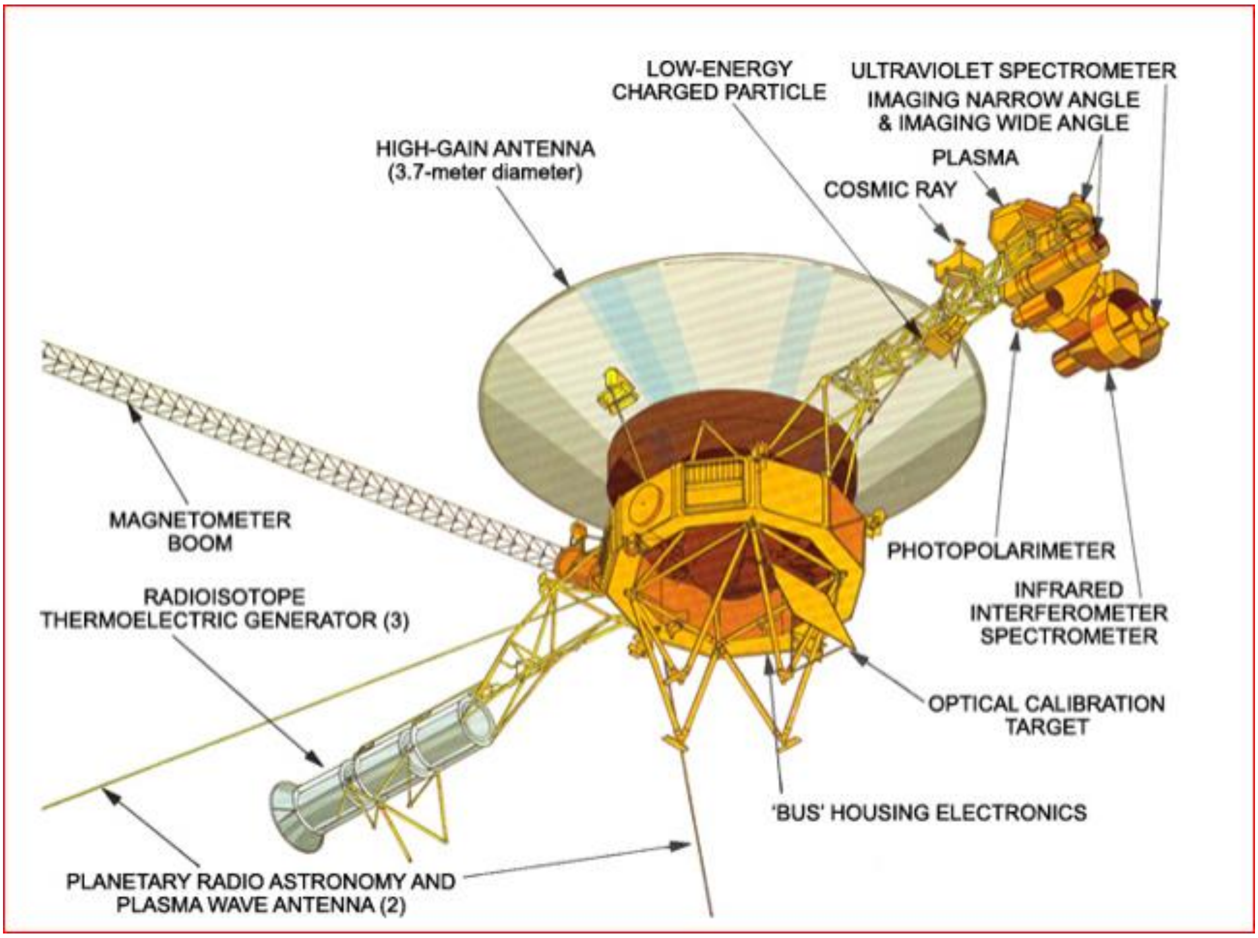
> Nikola Tesla predicts that electric messages and power will be sent from England to Australia without wires, we have no scientific warrant for disbelief, although we have not the smallest foundation in our present experience for hoping that such a thing may be possible. Stewart asked, "To what extent, from a commercial point of view, is wireless telegraphy likely to come into use?" He continued that "Gushing writers, in crowding together the coming achievements of the century, take for granted that all wires, alike for telegraph and telephone, will be abolished. Granted that if perfection is reached in practice, and that it is possible to dispense with telephone-wires between any two instruments, it will be readily admitted that a system by which a receiver could respond to and translate into speech all or any of the etheric vibrations set up by thousands of instruments would be of no value, to say the least of it.

Mobile phones

What would James Stewart think of most of New Zealand's present population, young and old, being close to their wireless mobile phones in any location for most of the day? And many have now dispensed with wired telephones to their homes in favour of mobile phones.

Long distance satellite radio transmission

Voyager 1 satellite having operated for 42 years from 1977, still communicates with the Deep Space Network to receive routine commands and to transmit data to Earth. At a distance of 22.0 billion km from Earth, it is the most distant man-made object from Earth. Voyager 1's extended mission is expected to continue until about 2025 when its radioisotope thermoelectric generators will no longer supply enough electric power to operate its scientific instruments.



[Figure 5] Voyager 1 Satellite launched 43 years ago travelling at 61,000km/hr. NASA picture.

Wireless Power Transfer

Wireless power transfer is a generic term for a number of different technologies for transmitting energy by means of electromagnetic fields. The technologies differ in the distance over which they can transfer power efficiently, whether the transmitter must be aimed (directed) at the receiver, and in the type of electromagnetic energy they use: time varying electric fields, magnetic fields, radio waves, microwaves, infrared or visible light waves.

At Auckland University, Professors John Boys and Grant Covic are world leaders in “Inductive Power Transfer” (IPT).

[Figure 6] Professor Grant Covic, left, and Professor John Boys of Auckland University won the 2013 Prime Minister's science prize for engineering wireless charging technology for electric cars and other devices. NZ Herald Picture November 2013.

Together John Boys and Grant Covic have published many technical papers describing Inductive Power Transfer systems to transfer energy without wires.

BRIDGES

James Stewart in his Presidential lecture described the evolution of bridges.

> Sixty years ago the design of bridges adhered, with few exceptions, to the arch or suspension type. But stone or "brick arches were going out, and designs in cast or wrought iron were coming in. The suspension type had been tried for railway-work and found unsuitable without such application of stiffening, as led it practically to partake quite as much of the girder type as of suspension. The disastrous breakdown of the Dee Bridge, near Chester, in which a deep cast-iron girder was reinforced in a rather unscientific manner by malleable-iron ties, led to the abandonment of cast-iron for all but very small spans, and even for such it has long disappeared. With the last of the "forties" came the tubular bridges of Conway and Britannia; but with the succeeding great Victoria Bridge over the St. Lawrence at Montreal this design may be said to have been abandoned.

Modern Bridge design

Cable-stayed bridges have gained popularity over suspension bridges by offering cost savings in steel and concrete, depending on the span.

The world's longest cable-stayed bridge is the JiaShao Bridge, 10,138 m long across the Qiantang River at the mouth of Hangzhou Bay in China. The main span is 2,680m in length. The bridge forms part of the 69.5km Jiaxing-Shaoxing River-crossing Expressway and consists of eight traffic lanes. The bridge is 55.6m wide and features six single-column pylons. It was opened to traffic in July 2013.

[Figure 7] JiaShao (Jiaxing-Shaoxing) Bridge, China. Wikipedia picture.

Prestressed concrete bridges can be precast in the factory and then moved to the construction site. In the last few decades, the precast concrete segmental bridge construction has been widely used around the world and for the Newmarket Viaduct.

These construction methods can benefit by reduction of costs, construction time, environmental impacts, and the maintenance of traffic.

Left: [Figure 8] Newmarket Viaduct replacement bridge. NZTA Picture.
Right: [Figure 9]Newmarket Viaduct segment. NZTA picture

Newmarket Viaduct is a key part of Auckland's motorway system. The first viaduct built in 1966 was not designed to recent earthquake standards and was replaced in 2012.

Steel box girder bridges were a popular choice during the roadbuilding expansion of the 1960s, A serious blow to this use was a sequence of three serious disasters, when new bridges collapsed in 1970, West Gate Bridge and Cleddau Bridge and 1971 South Bridge at Koblenz. Fifty-one people were killed in these failures, leading in the UK to the formation of the Merrison Committee and considerable investment in new research into steel box girder behaviour.

[Figure 10] Auckland Harbour Bride Clip-ons from Northcote Point. Sir George Grey Special Collections 1021-30

Traffic on Auckland Harbour's new bridge after it first opened in 1959 was far greater than expected. In 1967 a contract was let to a Japanese firm, Ishikawajiama-Harima Heavy Industries, for two steel box girder bridges. These bridges were built on each side of the Harbour Bridge, with the only connection at the existing piers using steel structures, colloquially called the 'Nippon clip-ons'. Freeman Fox and Partners were designers and the new bridges were state of the art structures using high tensile steel.

Bob Norman, former Commissioner of Works described saving Auckland's Bridge from a similar disaster to other steel box girder bridges in his book, *To get to the other side*.

It so happened that the Auckland Harbour Bridge Act required the plans to be approved by the Minister of Works on the grounds of public safety. This in turn involved the commissioner of works advising the minister, and as the department's chief designing engineer at the time I had to certify the design as sound.

So I received a bundle of plans and ran the rule over them. It did not take more than a few minutes to grasp the fact that we were dealing with a completely new animal, right at the forefront of technology. The main span of 800 feet (244 metres) was only 9½ feet (2.9 metres) deep in the middle which made it by far the most slender bridge of its type in the world. It fell right outside any codes of practice or design rules available.

After a lot of discussion with the various authorities, Bob managed to get the design changed to provide a 4.1 metre depth at the centre span.

> What would have happened if the old Works Department, in advising the minister on the consultant's first proposals, had simply been prepared to accept without question a design produced by one of the world's top consulting engineering firms? At the least would the Auckland Harbour Bridge Authority have had a major facility out of service for a long time for extensive reconstruction? Or at the worst would a row of Auckland Regional Authority buses filled with the bones of passengers now be rusting on the bottom of the Waitemata Harbour?

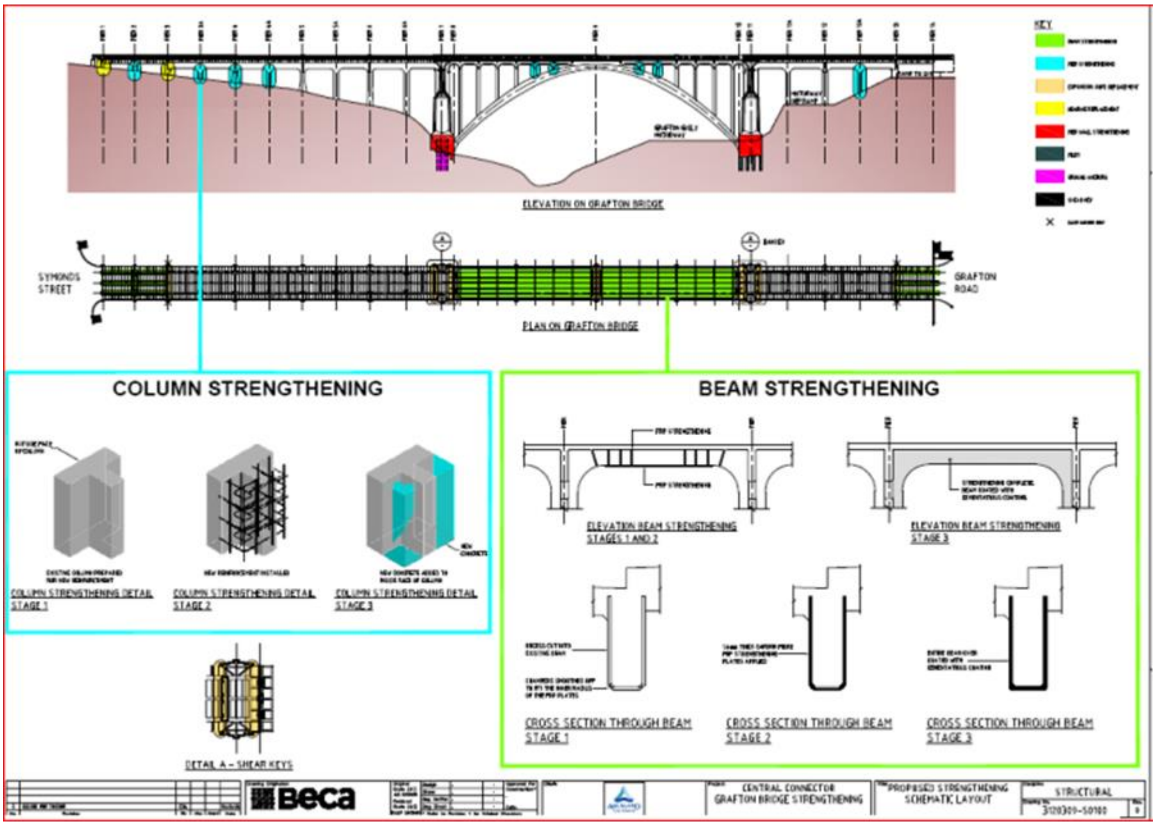
Carbon fibre repairs to Grafton Bridge. In his old age James Stewart would have seen and been fascinated with the construction of Grafton Bridge in Auckland, in 1910 the world's longest reinforced concrete span at 98 metres.

Grafton Bridge was designed by R F Moore with calculations done by Karl Rosegger Agster of Ferro-Concrete Company of Australasia. The bridge was leading edge technology for its time designed for pedestrians and horse and cart traffic as a three pinned concrete arch structure.

[Figure 11] Load testing Grafton Bridge to 5.4KPa in 1910. Sir George Gray Special Collections A750.

In 2004 it was decided to strengthen the bridge to HN72 highway loading using carbon fibre reinforcement. Beca Consultants were appointed to design the strengthening with Will Pank, Beca's Technical Director Structural Engineering, responsible for the project. The structural works were New Zealand's biggest ever carbon fibre reinforced polymer (FRP) bridge strengthening project.

Major structural investigations and testing were undertaken to assess the original concrete and steel condition. Although the arch itself was found to be adequate for the modern loading, the piers and columns needed to be strengthened for earthquake loading deck beams were found to have inadequate strength. Beca carried out three dimensional response spectrum analysis model for the whole bridge structure. The main deck beams required strengthening to increase both bending a shear strength.



[Figure 12]

TUNNELS

James Stewart remarked that

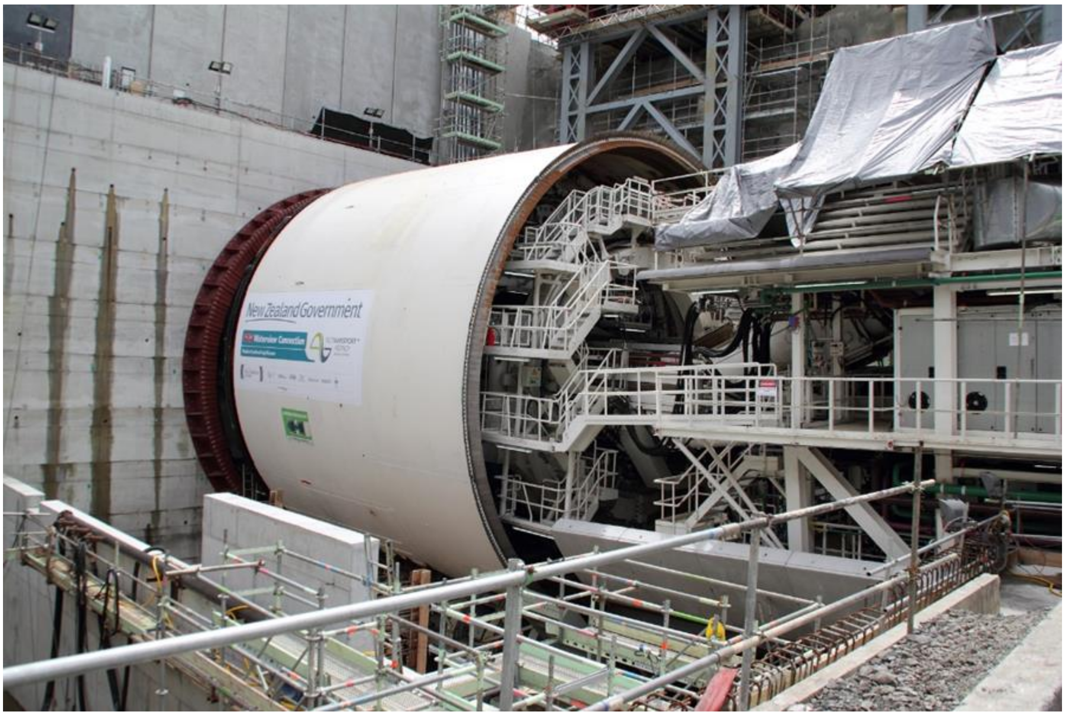
> In direct contrast to bridges are tunnels, and in this line an enormous advance has been made, not only in the magnitude of the works, but in the facility and certainty with which operations can be carried out under all circumstances, even to driving under the Thames at Blackwall with only a few feet of mud between the water and the lining of the tunnel. Driving railway-tunnels for miles under cities like London or Glasgow is now such an every-day occurrence as to call for no remark. During the last half-century the Mont Cenis Tunnel, seven miles and a third, (11.8km) and that of the St. Gothard, nine miles and a quarter, (15km) have been constructed, and at the present time the Simplon is being pierced by twin tunnels of twelve miles and a half (19.8km) in length.

No doubt Stewart would have been proud of New Zealand’s Otira Tunnel commenced in 1907 and completed in 1923.

The Otira Rail Tunnel rail runs under the Southern Alps from Arthur's Pass to Otira - a length of over 8.5 kilometres. At a grade of 1 in 33, the Otira end of the tunnel is over 250 m lower than the Arthur's Pass end. Construction started in 1907 and it opened on 4 August 1923. At the time of its construction, it was one of the longest tunnels in the world.

[Figure 13] Excavating Otira Tunnel 1908. Alexander Turnbull Library reference 1/2-056630-F

For many reasons, including public opposition to destruction of parks and natural features, Auckland has recently seen many tunnels constructed, and more are in progress at the time of writing. However tunnel construction by tunnel boring machines is a far cry from the hand excavation of the Otira Tunnel.



[Figure 14] Alice Tunnel Boring Machine during construction of the Auckland Waterview Tunnel. Wikipedia picture ***https://en.wikipedia.org/wiki/Waterview_Connection***

Twin road tunnels 2.4km long were completed in 2017 connecting the Western Ring route motorway to the North-western motorway. The Tunnel boring machine, 87m in length cut a 14m diameter hole that was lined with over 24,000 concrete segments.

[Figure 15] 87m long Alice tunnel boring machine ready to start its journey in December 2013. NZTA picture.

Other Auckland tunnel projects include the 2.82km City Rail Link bringing passenger rail through Auckland's central city due for completion in 2024, the 3km long 3.4m diameter sewage tunnel under Hobson Bay completed in 2010 and the 13km 4.5m diameter Central Interceptor sewage tunnel from Western Springs to Mangere due for completion in 2025. The 440m Victoria Park motorway tunnel constructed under Victoria Park by cut and cover was completed in 2011.

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