Callender-Hamilton Truss Bridges: The New Zealand History

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

1. Introduction

1.1 Background

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

Figure 1: Gates of Haast bridge.

1.2 Purpose of this project

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

2. Research methods

2.1 Library and interests

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

2.2 University of Canterbury archives

Figure 2: Model of a Callender-Hamilton bridge.

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

2.3 Opus International Consultants

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

2.4 Family members

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

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

3. About Archibald Milne Hamilton

3.1 Early Life

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

3.2 University study

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

3.3 Graduate employment

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

Figure 4: Model of the Lyttelton Harbour.

3.4 Career overseas

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

4. The Need for new bridge design

4.1 Military bridging in World War I

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

4.2 The Rowanduz Road (1927–32)

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

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

Figure 5: A Military-style bridge.

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

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

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

5. A new bridge design

5.1 Requirements

Hamilton set the following goals for his design to achieve:

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

5.2 Components

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

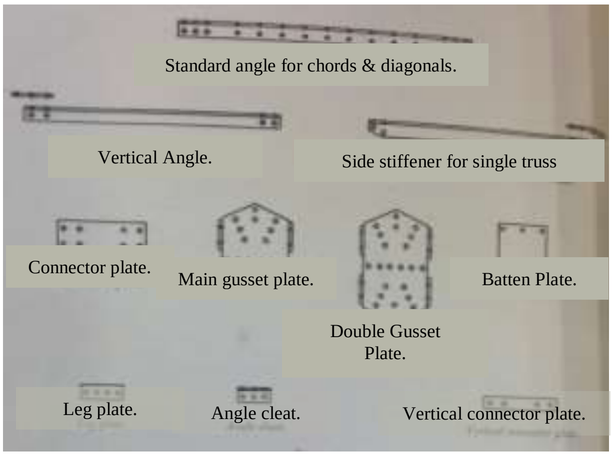

Figure 6: Standard Callender-Hamilton bridge parts

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

5.3 Galvanizing and durability

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

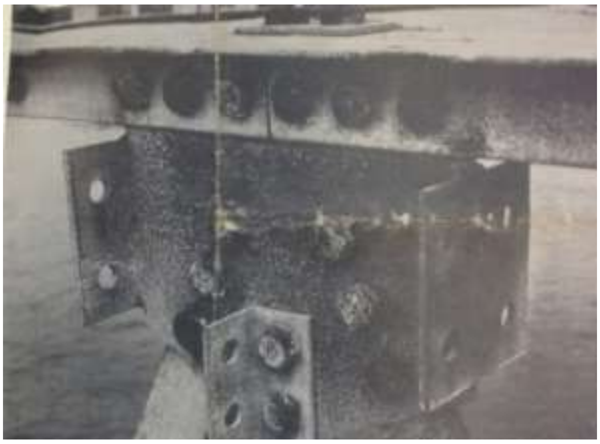

Figure 7: Gusset plate beginning to rust after 20 years.

5.4 Construction

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

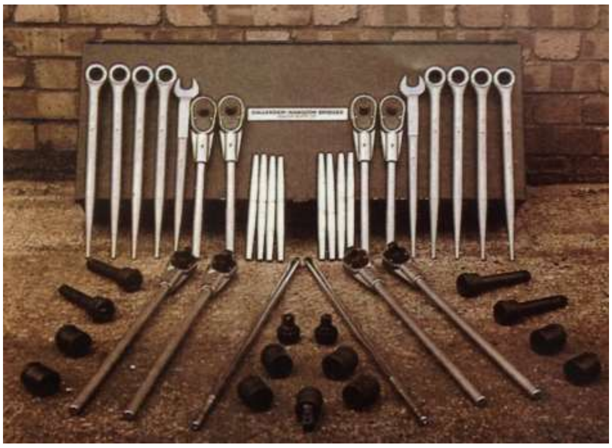

Figure 8: Standard tool kit.

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

5.5 Launching methods

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

Figure 9: Launching in progress.

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

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

6. Early stages of testing (1933)

6.1 Testing background

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

Figure 11: Test bridge showing during live loading.

6.2 Performance during testing

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

6.3 Bending moment and shear curves

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

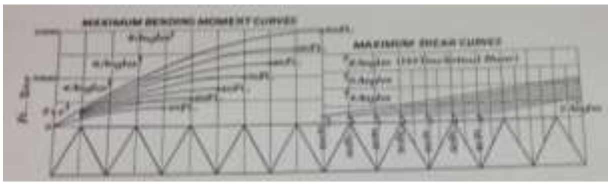

Figure 12: Maximum Bending Moment and Shear curves for the test bridge.

7. British military bridging

7.1 Prior to World War II

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

Table 1: Military bridging options in 1933.

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

7.2 During World War II

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

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

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

Figure 13: A damaged bridge during World War II

7.3 Current military bridging

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

8. Patenting

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

8.1 Similarities with the Bailey bridge

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

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

Figure 14: Bailey bridge [11]

8.2 Ex-Gratia awards

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

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

9. Production and evolution

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

9.1 Manufacturing

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

9.2 Types of Callender-Hamilton Bridges

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

10. Callender-Hamilton bridges in New Zealand

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

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

Figure 15: Callender-Hamilton bridges in New Zealand

10.1 Choice of Callender-Hamilton Bridges

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

10.2 Maintenance

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

10.3 Replacement

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

10.4 Bridge management

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

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

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

10.5 Case study

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

10.6 Emergency bridging in New Zealand

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

11. Conclusions

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

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

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

12. Acknowledgements

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

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13. References

[1] Acrow (2006), *Callender-Hamilton Bridges*. Retrieved 2006, from http://www.acrowcanada.com/callender-hamilton.html

[2] Baker, W.M. and Molcsan, N.D. (2013). Bridging the Gap: Callender-Hamilton Truss Bridges. Final Year Project. Civil and Natural Resources Engineering, University of Canterbury.

[3] Balfour Beatty (2003). Retrieved 2008, from http://www.bbusl.com/content/1/81/more-services.html

[4] Bailey DC et al. "The Bailey bridge and its development" Institution of Civil Engineers Symposium. ICE, London, (1947),

[5] BICC, "Callender-Hamilton Bridges", British Insulated Callender's Cables Limited. (1946).

[6] Boyse, C.O. *The Design and uses of Callender-Hamilton Unit-Construction Bridges,* Callender's Cable & Construction Co. Ltd, (1938), 2-14 pp, London.

[7] Hamilton family archives (1882-2010), *Collection of A.M. Hamilton's documents, photographs, models and speadsheet database.* Retrieved from MacMillan Brown Library, University of Canterbury.

[8] Hamilton, A.M. (1962), The Timaru Herald: New Haast Pass Road Superb Scenic Route.

[9] Hamilton, A.M. (1937), Road through Kurdistan; travels in Northern Iraq, Faber and Faber Limited.

[10] Hamilton, A.M. (1925), *The Radio Supplement.*

[11] NZTA (2013), *Providing Bailey bridges.* Retrieved September 2013, from New Zealand Transport Agency: http://www.nzta.govt.nz/network/maintaining/management/bailey-bridge.html#cost

[12] Think Defence (2012), *UK Military Bridging – Equipment (The Bailey Bridge).* Retrieved July 2013, from http://www.thinkdefence.co.uk/2012/01/uk-military-bridging-equipment-the-bailey-bridge/

[13] Think Defence (2011), *UK Military Bridging – Equipment (Pre WWII Equipment Bridging.* Retrieved July 2013, from Think Defence: http://www.thinkdefence.co.uk/2011/12/uk-military-bridging-equipment-pre-wwii-equipment-bridging/

[14] White-Parsons, G.D. (1963), Callender-Hamilton Bridge Business – New Zealand.

[15] White-Parsons, G.D. (1952), *Callender-Hamilton Bridge Handbook.* British Insulated Callender's Construction Company, Limited.

[16] WFEL (2013), *MGB Technical Specification.* Retrieved October 2013 from: http://www.wfel.com/products-and-services/medium-girder-bridge/technical-specification/