Bridge Types in NSW

Historical overviews

2006

These historical overviews of bridge types in NSW are extracts compiled from bridge population studies commissioned by RTA Environment Branch.

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Masonry Bridges

Heritage Study of Masonry Bridges in NSW

2005

HISTORICAL BACKGROUND TO MASONRY BRIDGES IN NSW

1.1 History of early bridges constructed in NSW

Bridges constructed prior to the 1830s were relatively simple forms. The majority of these were timber structures, with the occasional use of stone piers. The first bridge constructed in NSW was built in 1788. The bridge was a simple timber bridge constructed over the Tank Stream, near what is today the intersection of George and Bridge Streets in the Central Business District of Sydney. Soon after it was washed away and needed to be replaced. The first "permanent" bridge in NSW was this bridge's successor. This was a masonry and timber arch bridge with a span of 24 feet erected in 1803 (**Figure 1.1**). However this was not a triumph of colonial bridge engineering, as it collapsed after only three years' service. It took a further five years for the bridge to be rebuilt in an improved form. The contractor who undertook this work received payment of 660 gallons of spirits, this being an alternative currency in the Colony at the time (*Main Roads*, 1950: 37)

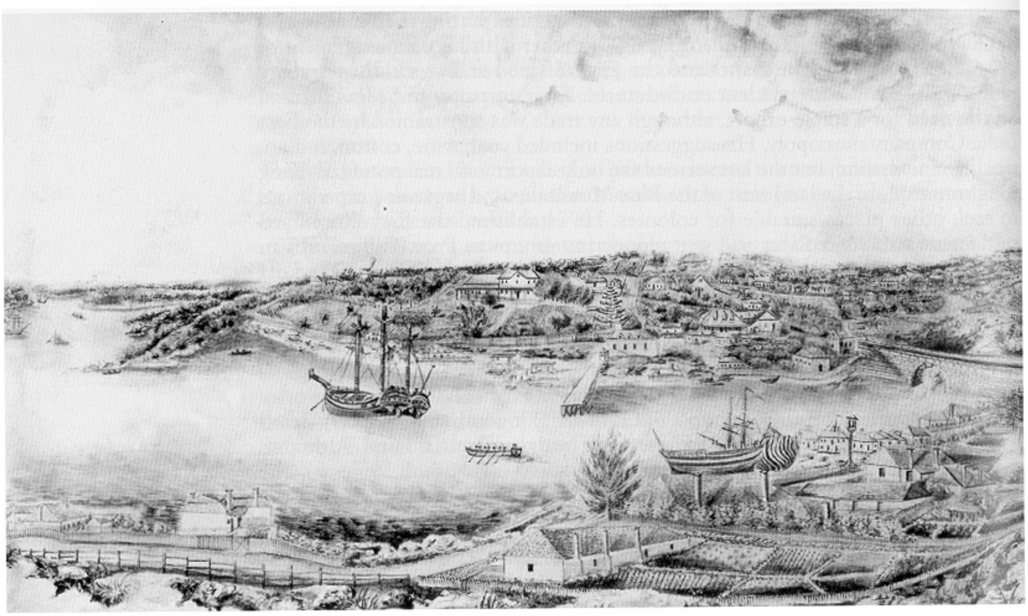


Figure 1.1 "View of Sydney from The Rocks, 1803", by John Lancashire (Dixson Galleries, SLNSW). The masonry bridge over the Tank Stream can be seen on the right.

Other early bridges consisted of timber including one in Parramatta, built by Major Grose in 1794, washed away in 1795 and replaced by a second bridge built a few years later and repaired in 1802. The Duck River Bridge, between Parramatta and Sydney was completed in October 1797. This was later destroyed by fire in 1839.

Prior to the arrival of David Lennox in the Colony in 1832, NSW was without expert knowledge in bridge design and construction. The earliest masonry bridge extant in NSW is the Horseshoe Bridge on Mitchell's Pass, near Lapstone (**Figure 1.2**). Completed in 1833, it is located on Mitchell's Pass and part of the Great Western Road. It was David Lennox's first project following his appointment as Sub-Inspector of Roads on 1 October 1832. This bridge marked the introduction of modern bridge engineering technology in NSW, earning Lennox the description of the "first "scientific" bridge builder in the colony".

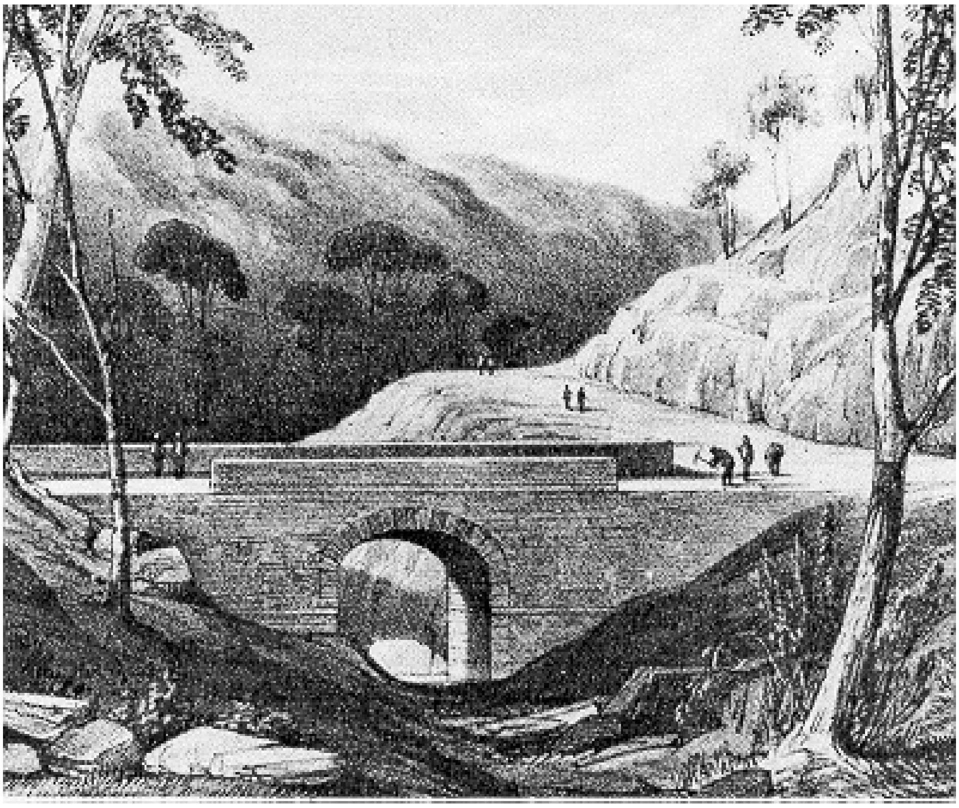


Figure 1.2: Early print of Lennox Bridge, Lapstone (DMR, 1976:27).

During the first 60 years of the Colony, the majority of bridges were built from stone or timber, in the same manner as bridges being constructed in Britain and Europe. Stone was the bridge building material of choice in NSW, with construction costs kept low by the use of convict labour. However, with the cessation of convict transportation in the 1840s and subsequent rise in labour costs, bridge designers were forced to explore the use of other materials in bridge construction, leading to the eventual adoption of timber as the economical alternative. The size and quantity of readily available Australian hardwoods in the 1800s allowed the design and construction of efficient timber truss bridge designs reaching respectable spans.

1.2 History of masonry bridge design

The colonial application of bridge construction techniques was based on imported knowledge from Britain which in turn had been based on knowledge that went back to Roman times. The bridge building techniques employed by Lennox were not innovative. The main problem in New South Wales was the lack of skilled persons in the colony, knowledgeable in this area prior to Lennox's appointment. The development of major roads in New South Wales coincided with a flurry of road and bridge works in Britain. In 1838 alone, £46,000 was spent on bridges by county authorities. The development of the macadamised system of road building by John MacAdam, and Telford's successful improvement of the highway between London to Holyhead raised the public profile of road engineering. Henry Parnell's account on Telford's Holyhead Road in 1833, was the first of a large body of technical manuals on road engineering to be published during the nineteenth and early twentieth century (**Figure 1.3**). A copy of Parnell's work was sent to Governor Bourke in 1835 by Lord Glenelg, Secretary of State for England.

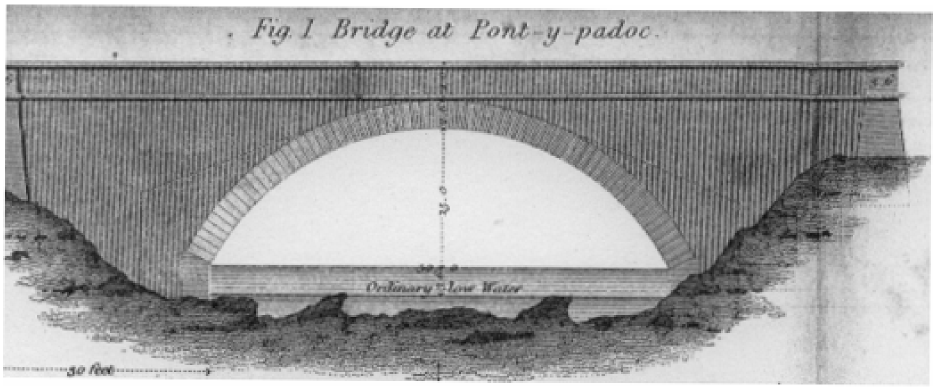


Figure 1.3: Parnell's account of Telford's Holyhead Road included drawings of the various bridges and tollbars (Parnell, 1833:9).

Bridges constructed in New South Wales prior to 1833 consisted mainly of simple span structures. In his manual for the construction of roads, Gillespie wrote that:

> *The most simple and natural form of a bridge consists of two timber beams, laid across the stream, or opening, which is to be passed over, and covered with a plank to form the roadway. Walls should be built to support each end of the timber, and are named the abutments* (Gillespie, 1868: 173).

Such simplistic constructions were only suitable for bridging short widths of waterway. For greater lengths, supports from the base of the opening such as piers, upright props or timber shores were used. These were supported on piles if the foundations were insecure. This method was not recommended for deep openings, or across rapid watercourses. In such situations, the use of bolsters, struts or a straining-piece was used (**Figure 1.4**).

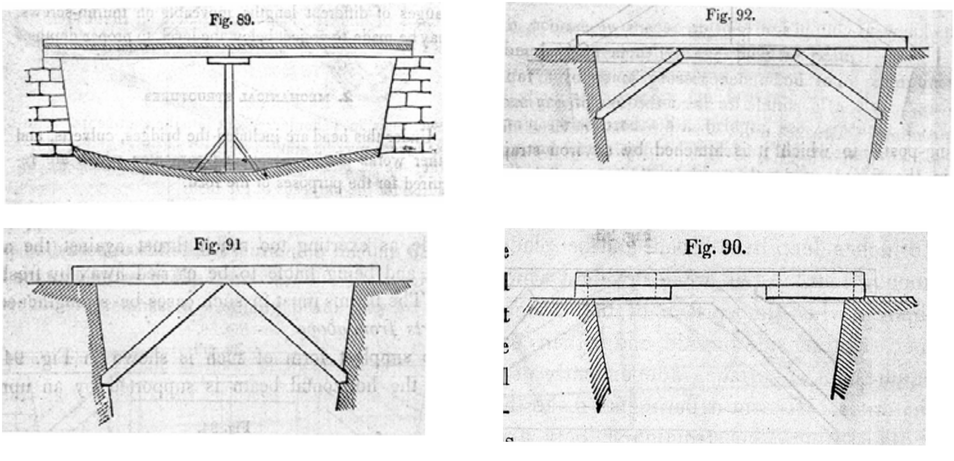


Figure 1.4: Simple bridge construction methods using timber planks (Gillespie, 1868:174-5).

In Britain and Europe, the technical design of masonry bridges reached new levels of sophistication from the late eighteenth century and into the nineteenth century. In Britain, the design of masonry bridges underwent three major developments in the first part of the nineteenth century. This included a lengthening of the spans of the largest arches, impact of French practices on bridge form and architecture, and improvements in foundation work (Ruddock, 1979: 46). Construction of long spans was spurred mainly by desires to construct record spans. During the nineteenth century, bridges were often prepared as part of design competitions.

The value of theoretical mathematics and physics to building applications was first recognised in France. Such sciences remained primarily academic pursuits until the seventeenth century. The formation of the Academie de Sciences as a school for the natural sciences by Colbert in 1666, established France at the forefront in the development of engineering sciences. Road and bridge construction was centralised in 1720, when the Corps des Ingenieures des Ponts de Chaussees was formed from the corps of military engineers. The first engineering school was founded in Paris, opening in 1747. Jean-Rodolphe Perronet was the first head of the school and later became the Premier Ingenieur of the Corps. He developed a style of arch bridge that was applied extensively throughout France and later adapted to British designs.

Perronet's style was characterised by three main elements, see **Figure 1.5**. First, there were pointed cutwaters, rounded at the shoulders. They extended up the spandrels, continuing above the springings of the arches, but not as far as the parapet. The spandrel faces were plain and vertical. The interior was usually filled with masonry.

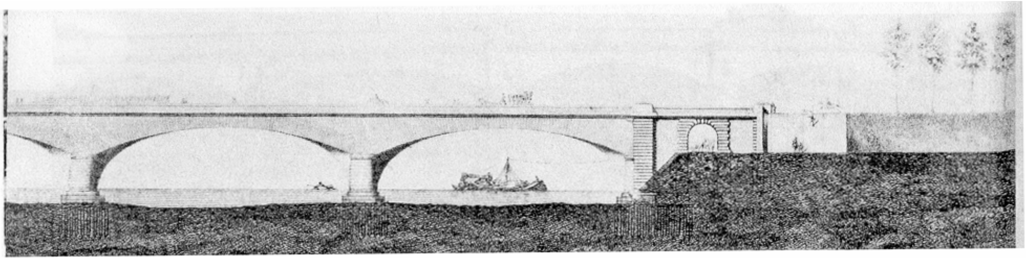


Figure 1.5: Half of Pont de Neully (from Perronet 1783 in Ruddock 1979).

The second characteristic related to the arch curves. These were either circular segments or ellipses. Earlier masonry bridges mainly consisted of a three-centred curve, producing a limited arch span. With Perronet, the segments of a greater radius circle was applied, allowing the bridge to have greater waterway clearance. The arch profile was also very low. By applying findings of structural and material analysis to design, Perronet reduced the vertical distance from the springing line to the crown to a value of 1/12, a value rarely exceeded in present designs. Perronet first applied this design element to Sainte-Maxene Bridge over the Oise.

With a low profile arch, the abutments were designed to carry most of the horizontal thrusts, with the piers designed only to support the vertical load. This enabled the piers to be unusually narrow. Previous to Perronet's designs, the customary ratio of pier width to span width was 1/5. This ratio was reduced to between 1/10 to 1/12. This method of design required the centering of all the arches to be erected at once and the support work could not be removed until all the arches were built (Ruddock, 1979: 63).

The third characteristic related to the lines of the road and parapets. These were generally horizontal in contrast to the majority of which were rounded to let rainwater run off the roadway easily. While assisting traffic flow this could however lead to water pooling on the bridge.

In addition to the three main elements, Perronet incorporated a fourth feature that was used occassionally. This involved chamfering the edges of the arches, which appeared as tapering crescents on the elevations (Ruddock, 1979). This characteristic was known as cornes de vache (cow's horns) or the splayed arch.

Its more streamlined form provided hydraulic benefits by lessening the flat surface opposed to the current of the river whenever it was in flood. Cornes de vache were used prior to Perronet, but became widely recognised through his application of the technique on the Perronet bridge of Neuilly, near Paris.

This fourth characteristic is of particular interest, because it was used by Telford for the design of the Over Bridge near Gloucester. Lennox, who had overseen the construction of this Bridge, later used this design as the basis for Lansdowne Bridge over Prospect Creek in New South Wales.

In 1783, Perronet published *Description des projets*, which included 67 plates showing all the details of his bridges. This publication provided British engineers with details of the French designs and the influence of this soon began to appear in British works.

Masonry arch bridge design was further improved in Britain during the nineteenth century. In particular, pier foundations were advanced to provide more stable and durable bridges. The construction of Westminster Bridge from 1738 to 1750 included the first use of open caissons. These consisted of open-ended boxes, which were pre-formed before being floated out to the pier location and sunk. The top of the box remained above water level, allowing the masonry work to be constructed within the caissons before they were removed. Caissons were used in conjunction with cofferdams to allow greater protection to the pier foundation. While the use of caissons provided an effective means of pier construction, it took several decades to refine the technique. With Westminster Bridge, problems with its foundations finally led to its demolition less than a century after its completion (Steinman & Watson, 1941:103-4).

John Rennie introduced new techniques to bridge construction, which marked a departure from French designs. In 1809, Rennie was invited to review the design of a new bridge intended to connect the Strand with the Surrey side of the Thames and was to be known as Waterloo Bridge. In the course of his review, Rennie recognised it was based on Perronet's bridge at Neuilly. Since its completion, the Pont de Neuilly had experienced problems with the settlement of the arches and unstable foundations. Rennie prepared new plans, including one for a bridge consisting of nine semi-elliptical arches, which was approved in favour of the original design submitted. Construction of Waterloo Bridge commenced in 1810, with Rennie as the chief engineer (**Figure 1.6**). The use of cofferdams allowed greater certainty in driving piles and laying foundations on the dry riverbed within these dams. The successful usage of cofferdams was also due to Rennie's application of steam power to drive the pumps. This effective use of cofferdams made caissons obsolete.

1.3 Lennox's work in New South Wales

The mammoth task of surveying the whole colony from 1828 to 1831 had resulted in the growth of the Surveyor General's Department to over thirty staff members. Directing his attention to establishing a road system, Mitchell wrote in 1833:

> *...have now completed the marking of the great roads throughout the Colony according to one general system; when they will be made God knows* ("Papers of Sir Thomas Livingstone Mitchell Vol.II" Mitchell Library).

Many colonial engineers and surveyors, such as Assistant Surveyors Elliot and Lambie had worked with Telford and MacAdam, and were knowledgeable with road construction techniques. There was however a notable gap in bridge engineering within the Department, particularly in regard to masonry walls.

In 1832, Mitchell had a chance encounter with David Lennox whilst walking along Macquarie Street. Lennox was employed as a mason at the Legislative Council Chambers and was busy shaping a coping stone for the dwarf wall. Mitchell was so impressed with his workmanship that he inquired of his experience. Mitchell later recalled:

> *Mr David Lennox, who left his stone wall at my request, and with his sleeves still tucked up – and trowel in hand -, came with me to my office, and undertook to plan the stone bridges we required, make the centering arches, and to carry on such works by directing and instructing common labourers then at the disposal of the Government. Thus originated all the bridges this colony possesses worthy of the name.*
>
> ("Papers of Sir Thomas Livingstone Mitchell Vol.VIII" Mitchell Library)

The Surveyor-General lost little time in submitting Lennox's credentials to the Governor, describing him as "a very well qualified person recently arrived in the Colony." Acting on Mitchell's recommendation, Governor Bourke provisionally appointed Lennox as a Sub-Inspector of Bridges on 1 October 1832 at a salary of £120 per annum. In June 1833 the position was confirmed by London as Superintendent of Bridges.

David Lennox was born in 1788, at Ayr in Scotland. Following his wife's death in 1828, he migrated to New South Wales arriving in Sydney on August 11, 1832. Lennox gained his experience in Britain, working for 17 years on public works funded by the British government. When applying for a salary increase in 1835, Lennox wrote:

> *I have recommendations from the best qualified persons in Europe to give such recommendations, - From that late Thomas Telford Esq Civil Engineer F.R.S.P.S.E. without whose advice the British Government advanced no money upon Public Works in the Engineer Department…* (Bundle 38/7385, Mitchell Library)

In Britain, Lennox had worked in different capacities on two key bridges, both designed by Telford. These were the Menai Suspension Bridge, connecting the Isle of Anglesea on the northwest coast of Wales with the mainland, where he worked as a stonemason from 1819, and the Over Bridge at Gloucester (**Figure 1.6**) in the west of England where he worked as Foreman, with three others, during its three year construction (Selkirk, 1920: 204). Completed in 1827, the bridge consisted of a single span of 150 feet with a rise of 35 feet above the waterline. Telford had adopted the design from Perronet's Neuilly Bridge over the Seine (**Figure 1.5**).

Figure 1.6: Over Bridge, Gloucester, 1827. (Image courtesy of Gloucester City Council).

David Lennox's first project following his appointment as Sub-Inspector of Roads on 1 October 1832 was the Horseshoe Bridge on Mitchell's Pass, near Lapstone (see **Figure 1.2**). It was This bridge marked the introduction of modern bridge engineering technology in New South Wales, earning Lennox the description of the "first "scientific" bridge builder in the colony".

His greatest bridge was the Lansdowne Bridge across Prospect Creek, between Parramatta and Liverpool, completed in January 1836 (**Figure 1.7**). During its construction he made regular tours of inspection to several bridges under his direction on the Great Road South. He completed two other bridges later in 1836.

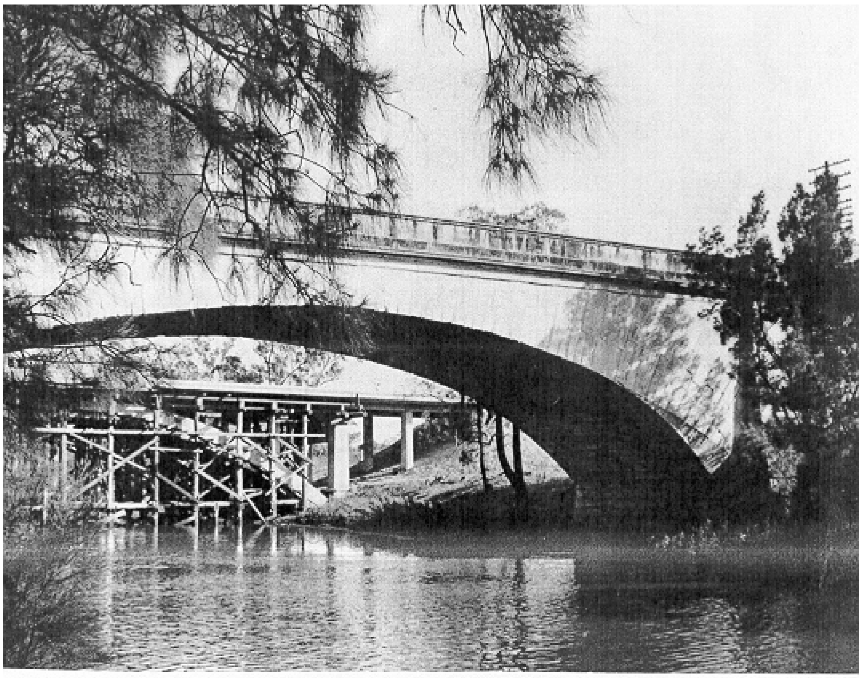


Figure 1.7: View of Lansdowne Bridge looking south in 1957. The new bridge for westbound traffic is under construction in the background.

In 1833 Lennox received instructions to construct a bridge across the Wingecarribee River at Berrima, and although there was some delay in the commencement of the work it was completed in June, 1836. It was designed along the lines of the Lansdowne Bridge, but it was smaller with a span of 15.2 metres (50ft) and a width of 27ft, including parapets and without the bevelling of the arches (**Figure 1.8**). It was damaged by flood in 1858, and then destroyed in February 1860 (Main Roads, 1950: 40).

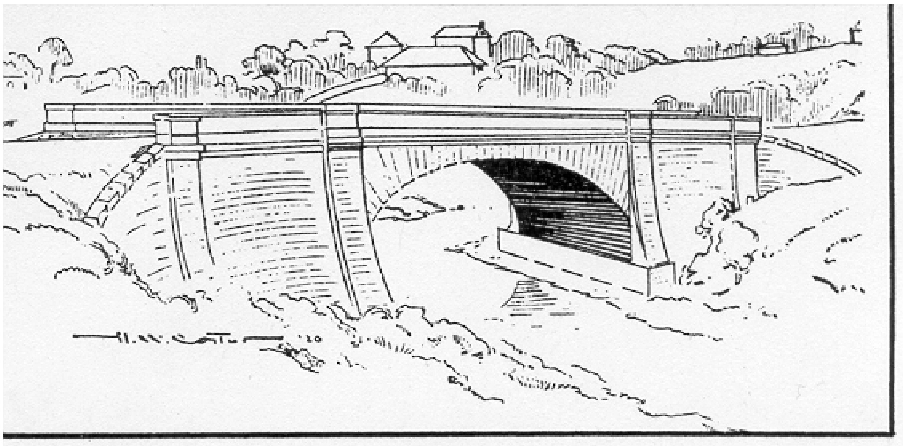


Figure 1.8: Sketch of Berrima Bridge (*Sir Thomas Mitchell's Field Book* C.53 ML SLNSW).

On 23 January 1834, Lennox reported having laid out the site of a bridge on the main southern road at the crossing of Medway Rivulet, three miles south of Berrima. For this crossing a wooden bridge supported by three masonry piers 20 feet apart was designed. In 1835 the Surveyor-General reported that the bridge had been completed. This was destroyed by floodwaters in 1860 and later replaced.

Again in 1834 Lennox laid out the site of a bridge at Crawford's or Black Bob's Creek, 7.5 miles south of Berrima. The span of the bridge was 9.1m (30ft). Although the bridge was open to traffic in April 1836, it was not completed until early 1837. The Surveyor-General reported that the piers and walls were of excellent stone resting on a solid mass of rock, and that the bridge was constructed of strong beams, supported by a brace. It was built on the same design as a number of bridges constructed by Lennox on the Gloucester-Berkeley Canal This was replaced by the Public Works Department in 1896 with a mass concrete arch built between the sandstone abutments. It is the oldest existing concrete bridge in NSW (Evans, 1987: 3).

The last bridge which Lennox designed and built in NSW was over the Parramatta River in Church Street, Parramatta. Originally designed in 1835 as a single elliptical arch of 90 ft span, it was built, after much controversy, as a simple stone arch spanning 80ft and having a width of 39ft. Construction began in November 1836, using the centering from the Lansdowne Bridge, adjusted to the new span, and was completed in 1839. The Bridge was named Lennox Bridge by the Parramatta Council in 1867.

From January 1, 1837, the construction of roads and bridges passed from the Surveyor-General to the Royal Engineers under Colonel Barney, to whom also Lennox was transferred. Duck Creek Bridge on the Parramatta Road, originally designed by Lennox as a timber structure on stone piers, was built about 1840 as a semicircular brick arch of 9 m (30ft) span with brick abutments. This had a total length of 25.50 metres (83 ft) and provided a 10.80 metre (35ft) wide roadway (**Figure 1.8**).

Figure 1.8: View of the Duck Creek Bridge at Granville looking north.

The keystone of the arch on the downstream side bore the Masonic symbol of a pair of compasses open upon the segment of a circle. In Freemasonry this has a Scottish significance, and is no doubt a Master Mason's mark, providing strong evidence that Lennox supervised the work (Selkirk, 1920: 228). In 1937 the bridge was widened under the direction of the DMR, by the addition of a 30ft span concrete arch to the downstream side of the bridge. There is another small bridge at Towrang with a span of the order of 5metres. One of the keystones is inscribed 1839, and it is believed that the bridge was built by Lennox (**Figure 1.9**). It is located on the original south road between Berrima and Goulburn, immediately east of the turn-off to Carrick.

Figure 1.9: Towrang Bridge built in 1839.

In November 1842, Lennox was appointed as District Surveyor to the Parramatta District Council on the recommendation of a Board of Examiners. The Board spoke in the highest terms of his qualifications in bridge building of the best construction, construction of roads, canals, dams, and most other descriptions of public works, which they considered should be sufficient recommendation to any District Council.

Lennox held this office for only one year before taking up a position as Superintendent of Bridges at Port Phillip, Victoria. In this capacity he was responsible for the construction of all roads, bridges and wharves. He is said to have built over fifty bridges in the state, however many were of timber and none have survived. Severe flooding in May 1852 washed away his bridge at Geelong, and severely damaged those at Batesford, Inverleigh and Cressy. Lennox's greatest Victorian work was the Prince's Bridge spanning the Yarra with a single stone arch of 150 feet. Completed in 1850, this structure was demolished when the river was widened in 1888 (Selkirk, 1920: 238).

In 1855, on his return to New South Wales from Victoria, Lennox settled in Parramatta, living firstly in Macquarie Street while he designed and built a cottage in Campbell Street. This cottage, which is still standing and is listed by the National Trust, was where he spent the remaining years of his life.

David Lennox died at his home on 12 November 1873 aged 85, and was laid to rest in the vault of his son-in-law Mr CW Rowling, in old St. John's Cemetery. By some strange oversight no inscription was placed upon the stone which marks his grave, so that some uncertainty exists as to where he is actually buried.

It has been said of the renowned 19th century engineers Telford and Rennie:

> *Here were Scotsmen of humble origin who applied their remarkable gifts in an age that offered opportunity to men of vigour and intelligence* (de Mare, 1975: 117)

The same could be said of Lennox.

Timber Beam Bridges

Study of Relative Heritage Significance of RTA Controlled Timber Beam Road Bridges in NSW

2000

HISTORY OF TIMBER BEAM BRIDGES IN NSW

1.1 Introduction

Timber beam bridges, in the form of fallen tree trunks across streams, are probably the oldest types of bridges used by humans. The focus of this report is on the use of timber beam bridges in New South Wales, for roads. Some historical references are also made to their parallel use for railways.

Timber beam bridges and timber openings, or TOs, as they are called in the railway organizations, were the foundation structures of the road and railway networks of land transport in NSW. The two forms of construction for the road and railway bridges are very similar as they were based on traditional examples in Britain and Europe and because engineers in the Department of Public Works (PWD) dealt with both types until around 1920.

Typical timber beam road bridge, Br No 2769

Typical timber beam railway bridge

The growth of the settlement of Sydney and the later expansion of settlement west of the coastal strip, depended on the effective and economical use of roads, and later on the railways. This dependence grew from the limitations of the coastal and inland shipping and the consequent necessity for improved land communication.

Within Sydney Town a log bridge was built over the Tank Steam in October 1788, six months after settlement. It was replaced by a stone arch bridge in 1803, giving rise to the name of today's Bridge Street (DMR 1976).

Further afield, a timber bridge was completed over Duck River (Granville) in 1797. In 1805 the Governor's Road Committee listed 10 bridges on the Parramatta Road, 'as this road was a vital food supply route', from Johnston's Creek (Annandale), to A'Beckett's Creek (Parramatta), to the following specification

> 16 feet wide with Four Sleepers of at least a foot and a half in diameter, either of ironbark or blue gum, bedded on timber of the like dimensions, to be covered with three inch planks, 16 feet long and properly secured by treenails of 1 ½ inch diameter (DMR 1976).

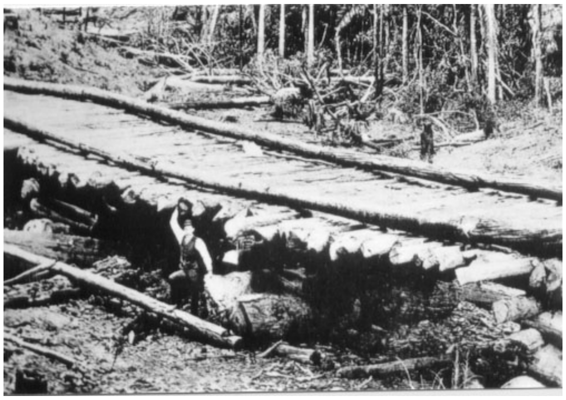
In 1808 Lt-Governor Joseph Foveaux mentioned 'framing log bridges' when referring to repairs for High George Street in Sydney (DMR 1976).

By 1790 the settlement of Parramatta had been established at the head of navigation of the Parramatta River where the width made it possible to build a bridge for the road to the Hawkesbury River. Major Francis Grose is credited with the building of a timber bridge over the river in 1794, but it was not stable and was swept away by floodwater in 1795. A more durable timber bridge on stone piers took its place in 1802 (DMR 1976).

Between 1813 and 1821, during Governor Macquarie's term, William Roberts was contracted to undertake many road works including 28 bridges on the Windsor and Liverpool Roads. The building of these bridges 'rendered incalculable benefits to the settlers' (DMR 1976).

Following the trail blazed by Blaxland, Wentworth and Lawson over the Blue Mountains in 1813, William Cox's team of 30 completed a 'road' to Hartley in January 1815. The road included bridges over the Lett and Cox's River using 'pieces made from an oak tree with a girth of up to 9 feet' (DMR 1976).

All these bridges were of a timber beam type, but neither exact details nor sketches are available. However, more is known of an earlier form of log bridge, the corduroy bridge, because some of the late survivors were photographed around the 1880s. Large longitudinal logs were topped by smaller transverse logs with side logs, acting as kerbs. The ride over the transverse logs was, of course, rough and sometimes the decks were covered with soil and turf, to make the crossing easier for drays and more comfortable for coach passengers. Later the transverse logs were replaced by planks, which further improved the riding surface.



Corduroy bridge

A turf covered beam bridge

1.2 Department of Public Works

During the 1840s and early 1850s building Infrastructure was the responsibility of the Colonial Architect. However, following the impact of the Gold Rush, the demand for public-oriented works exceeded the capacity of the Colonial Architect's Office and a new government agency, the Public Works Department (PWD), was established in 1859. In 1861 William C. Bennett began a 30-year tenure as Commissioner and Engineer for Roads and Bridges. He had already gained wide experience in both areas, particularly in the construction and maintenance of laminated timber arch bridges during the late 1850s.

Capt. B H Martindale, an Officer of the Royal Engineers, was Commissioner for Railways and for Internal Communications from 1858 to 1861. Under the direction of the Minister for Lands he journeyed around the colony of New South Wales and produced four Reports on Internal Communications, 1857,1858,1859 and1860. The reports are all contained in the *Votes and Proceedings* of the New South Wales Legislative Assembly.

The Reports dealt with all manner of aspects of road and rail transport as well as communications by electric telegraph. In summary, they reported on the contemporary status of land transport and made many recommendations on how to improve it. He drew attention to:

> the want of bridges suspends inter-communication steep and sliding banks of creeks would be obviated by very ordinary bridges of simple construction
>
> bridges urgently required at Singleton, Aberdeen, Murrurrundi and Bendemeer
>
> labour cost are three times those in England
>
> inhabitants of Gundagai are inconvenienced by creeks along the flats and submergence when the Murrumbidgee floods
>
> the principles for carrying out road works, first, to bridge the creeks and rivers which habitually stop traffic in times of flood, second, improve the places along the roads (Martindale 1857 to 1860).

In Martindale's report there are lists of bridges being built or recently completed and many are 'simple beam' bridges (Martindale 1857 to 1860).

Petitions for bridges were regularly published in the newspaper, for example in the *Sydney Morning Herald* (SMH):

> Petition to Sir William Denison includes figures for the stock crossing the Murray River each year, 400,000 sheep, 30,000 cattle and 4,000 horses. Condemnation of ineffective action from centralized governments (*Sydney Morning Herald* 1/10/1856).

Community frustration due to the lack of bridges being built was published in the *Sydney Morning Herald* and the *Newcastle Chronicle*:

> In the Edwards River District private individuals are prepared to build a bridge at Deniliquin (Sydney Morning Herald 1/10/1856).
>
> City folk don't appreciate the importance of bridges to the interior *(SMH* 14/1/1856).
>
> Money spent on bridges is money put to good use (*Newcastle Chronicle* 5/7/1870).

The need for road bridges had been established early. As for knowledge about road and bridge building, it was scarce in the young colony. However there was a substantial body of knowledge in Britain and Europe from whence most arrivals had come and among whom there were experienced military engineers and tradesmen. There was a great deal more engineering and scientific knowledge in the hands of a group of competent bridge engineers in the PWD by the 1890s.

By the time the PWD was established, timber was the dominant building and construction material, even though some notable stone arch bridges had been constructed under the supervision of David Lennox (Selkirk 1920). For example, in 1836 the Landsdowne Bridge over Prospect Creek and in 1839 the Bridge over the Parramatta River at Church Street Parramatta. The North Coast districts were yielding their abundance of cedar for furniture, doors, windows and other house fittings, and various hardwoods for structural uses. Wrought iron was not used as much as timber as it was an expensive import from England, even though it may have been more suitable in some applications.

The dominance of timber for bridges, wharves, interiors of building and other structural uses was further strengthened in 1861 when the Government decreed that local materials (stone, bricks and timber) had to be used in preference to wrought iron. This action was largely designed to curb John Whitton (Engineer-in-Chief for Railways) following his lavish spending to build two wrought iron bridges over the Nepean River at Menangle (1863) and at Penrith (1867). Their combined weight of iron was 2,035 tons and the combined completed cost was £194,562, an enormous sum for the still fledgling colony.

John Whitton

The 1863 Menangle railway bridge, extra piers 1905

The government move was partly effective because Whitton went on to use timber beams, arches, trusses, and some magnificent stone arch viaducts for the railway extensions through the Great Dividing Range. However, for major river crossings he successfully asserted the need for large, high-level iron bridges to stay above maximum flood levels, and to carry the heavy steam locomotives. This was particularly so in the boom years of the 1880s when roads were seen as feeders to the railways and were allocated less funding. Consequently, road bridges were dominated by the cheaper timber construction.

High-level flood-free structures were not the case for most road bridges so they were built either at a low level to let floods pass over or somewhat higher so as to pass moderate floods only. The slower, lighter road traffic could make do with timber bridges, mostly 30-foot (10m) span timber beam bridges and timber trusses up to 90 feet (27m) spans.

In order to meet the growing need to span the numerous creeks and rivers to move rural produce, goods and passengers clear of river fords, timber beam bridges offered the cheapest and quickest solution. This is because they used the abundant local hardwoods and they involved simple construction details. Thousands of these bridges were built, mostly as independent structures. Many were also built as approach spans to major bridges so as to reduce the overall project construction costs.

The most spectacular example of timber beam bridge construction is the long timber viaduct across the Murrumbidgee flood plain at Gundagai. Originally completed in 1869 it was replaced by a new viaduct in 1896, which, although out of service, is extant and is now the responsibility of Gundagai Historic Bridges Inc.

Commissioner Bennett's 1865 and 1870 Reports to the Colonial Governments contain lists of bridges for the Southern, Northern and Western Roads (Highways), and shows that a large majority were timber 'beams on piles' (Bennett 1865, 1870).

The clearest evidence of the role of the timber beam bridges in the developing road network is given by successive PWD Roads and Bridges Branch Annual Reports from 1892 to 1902 (PWD 1892 to 1902). The reports show that the total number of bridges built steadily increased from 2,700 to 3,700 with the larger bridges, timber trusses, masonry arches, iron girders and iron trusses being specifically identified and described. The latter averaged only around 13% with timber beam bridges as 87% of the total number of bridges at the beginning of the 20th century.

Timber beam bridges were cheap and represented good value for the restricted finances of the colony of NSW. But in the long term, the total price was high taking into account the accumulated maintenance costs, many times greater than the initial cost of construction. There has also been a steady depletion of the hardwood forests, which now makes the supply of good timber a critical factor in maintenance of timber beam and timber truss road bridges.

1.3 The Timber Beam Bridge

The best descriptions of the construction and uses of timber beam bridges are those contained in papers by Harvey Dare in 1904 (Dare 1904), Percy Allan in 1924 (Allan 1924) and Frank Laws in 1931 (Laws 1931).

William C. Bennett

Percy Allan

Harvey Dare

Collectively they confirm that the timber beam bridge was the most common type of road bridge, due to the simple form and the myriad of minor crossings of creeks and small rivers. This situation persisted into the 1950s when steel production recovered after World War II and prestressed concrete was introduced. Thereafter, very few new timber beam bridges were built, and a great many have been replaced by steel beams or precast prestressed concrete units, or stripped of their infamous planked decks and covered by a slab of reinforced concrete.

The bridges can be classified into two design phases:

- pre–1894 traditional design; and
- post–1894 when the design was improved to make the bridges cheaper, stronger and requiring less maintenance.

These bridges may be classified according to the following types:

- low-level where the superstructure is submerged by most floods; and
- high-level where the superstructure is above the design flood level.

1.3.1 Pre-1894 Timber Beam Bridge Construction

The construction details from the period of 1840 to 1894 consisted of a series of timber trestles each with 3 to 5 piles of 14-18 inch (360-460mm) diameter driven into the bed of the waterway. The piles were capped directly over their tops by a 12 inch x 12 inch (300 x 300mm) headstock. A headstock is a single piece of timber sitting over the tops of the piles. To replace it required raising the whole superstructure to obtain clearance. The piles were then braced on the outsides by opposite inclined 10 inch x 4 inch (250mm x 100mm) planks to form cross bracing.

Pre-1894 detail at top of trestle

For a low-level bridge, the cross bracing would be omitted whereas for a high-level bridge there could be two levels of cross-bracing separated by a pair of horizontal wales, one on each side of the piles, and with another pair just above ground level.

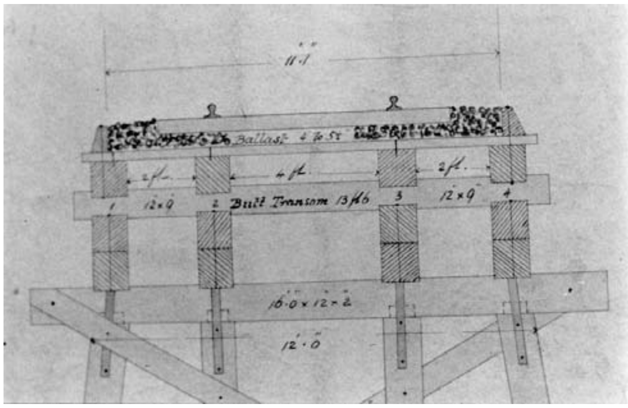
Supported on the headstock, and at right angles to it, would be a set of short (8-12 foot) 12 inch x 12 inch timbers, called corbels. Their number and location would be the same as the main longitudinal beams that were usually 12 inch x12 inch dressed or 15 inch (380mm) logs dressed only at their ends to sit flat on the corbels. Both 12 inch x 12 inch beams and 15 inch round beams were used in timber beam road bridges. The most common arrangement was for the dressed or squared timbers to be on the outside for appearance sake and the round logs with their bark attached "hidden" in the interior. The lengths of these beams would be either equal to the distance centre to centre of the trestles when cut square or longer if overlapping scarfing was used over each support. On top of the main beams were the 3 inch (75mm) thick transverse deck planks.

For railway bridge spans longer than 35 feet (11m), compound beams were used whereby two 12 inch x 12 inch timbers, one above the other, would be locked together by a combination of vertical bolts and wooden keys, in precut slots, across the interface.

1.3.2 Post – 1894 Timber Beam Bridge Construction

In 1894 Percy Allan began his redesign of both the timber beam and timber truss bridges (Allan 1924). His purpose was to greatly simplify construction and maintenance and to minimise the amount of timber used. In terms of the latter, Allan was aided by Professor Warren who conducted extensive research into the strengths of Australian hardwoods (Warren 1890).

A typically costly maintenance item was the replacement of headstocks that were attached to the tops of the piles by a combination of internal mortise and tenons, and external strap bolts. The whole superstructure at that trestle had to be raised by the height of the tenon so the headstock could be raised and withdrawn.



Cross-section of a rail timber beam bridge prior to 1894.
Note the mortise and tenon joints between headstock and piles which were typical of those used on road or rail timber beam bridges.

Allan's solution to this problem was simple. A pair of half-headstocks or capwales was checked into the piles at their tops, one on each side, and cross-bolted. They could be replaced without raising the superstructure. The time consuming carpentry required to make the mortise and tenons, and the use of the strap bolts were eliminated.

Furthermore, the lengths of the corbels were reduced, scarfing of the main beams over the trestles was eliminated and simple squared butt ends introduced and the number of shear keys for compound beams was reduced. Full-length piles were eliminated and were cut off just below ground and covered by a concrete sill or capping beam, then an independent trestle structure was built on top of the sill. This system could not be applied to the abutments due to the effects of lateral earth pressure, so full height piles were retained at the abutments. The deck was changed from a single layer of 3 inch (75mm) cross planks, to two layers of 2 inch (50mm) planks, one cross layer with a longitudinal layer over the top. This practice continued as circumstances dictated until formalised in the 1950s as standard for all timber decks.

The overall effect of the changes was to reduce the initial cost of construction by 20% and reduce maintenance costs as well as extending the service lives of these bridges.

A development in the 1920s was the use of spiking planks under the deck between the beams. It had become clear that the wear and tear and impact on the deck planks was severe. A beam outlives several decks and this led to an excessive number of spike holes in the beams with successive decks. The holes allowed the penetration of water into the beams, which is the bane of all exposed timber construction. Spikes were installed into the spiking planks rather than the beams, thereby reducing this problem.

Improved detail at top of trestle

The 1894 timber beam road bridge

First layer of cross planks on the girders

Second layer of longitudinal planks

The differences in details between the pre- and post- 1894 timber beam bridge designs generally assist in identifying the era of a timber beam bridge by site inspection, although two factors can lead to an incorrect decision. Firstly, there was a transition period after 1894 before the wholesale change over to the new design. Consequently, bridges of either type were built during the late 1890s. Secondly, despite the 1894 design becoming the new standard, site visits have revealed many younger timber beam bridges from the 1920s and 1930s, which have old style details such as single member headstocks across the tops of the piles of the trestles. Why the reversion to outmoded practices occurred is not known or recorded.

1.3.3 Low-Level and High-Level Timber Beam Bridges

Percy Allan effectively summarised the situations governing the use of low-level bridges:

> Many of the New South Wales rivers carry little water in dry seasons but are subject to very high floods of great width and carrying large quantities of drift timber. In some cases the floods are short duration whilst others remain at a high level for months. Experience and judgment are consequently required to determine whether, with small traffic to be served, a low level bridge available for most of the year can be safely adopted, or should a high level bridge be adopted above flood level (Allan 1924).

There is always a large risk with the height of a low-level bridge. These bridges need to be placed at a certain height above normal water level. This height was determined such that the bridge was available for traffic in times of small floods, yet was low enough to be submerged to a sufficient depth to allow drift timber to pass safely over in a major flood. The deck of such bridges seldom exceeds 2 metres above normal water level.

Some low level bridges were built at higher levels than designed due to an agitation being started by locals to raise the deck following the authorisation of the bridge. Many failures have occurred in the State with low level bridges due to their being built at a higher level than originally contemplated by the engineer with consequent exposure to damage by drift timber which was not allowed for in the original design.

For high level bridges, the criterion is to maintain traffic flow over all likely levels of flooding. The decks were usually placed 0.6 metres clear of the highest known flood. However, there is a limit to this ideal when the trestles become as tall as the spans are long, and where the whole structure is quite long. With excessively tall trestles the larger proportion of costs is in the substructure and the forest of relatively closely spaced trestles can present a serious obstacle to drift timber during flooding. The conventional solution was to increase the spans of the superstructure using timber trusses, steel beams or iron lattice spans, with fewer but sturdier timber trestles, masonry or cylindrical iron piers.

Solutions beyond the limits of timber beam bridges,
left, timber trusses on concrete piers over the Clarence River at Tabulam,
right, iron lattice trusses on cylindrical iron piers over the Snowy River at Dalgetty.

1.4 Summary

The timber beam road bridge, in its four forms of pre- and post-1894 and low and high-level, was the mainstay of road bridges in New South Wales from the time of European settlement at Sydney Cove in 1788, through to the end of World War II in the late 1940s. At peak usage they numbered in excess of 4,000 (including those forming approach spans to major bridges), and represented around 80% of the total road bridge population controlled by the Department of Main Roads.

These bridges played a significant part in the development of land transport, road and rail, during the second half of 19th century in colonial New South Wales.

Over the years their shortcomings have been exposed. These are:

- Low strength for the heavier and faster modern traffic
- High maintenance costs
- Construction details that allow penetration of water and hence deterioration of members
- Lower durability due to the declining quality of available hardwoods for replacement elements
- Overall superiority of steel and concrete bridges.

As a class of bridge the timber beam bridges served the Colony and State of NSW well for 150 years as a cheap ‘temporary’ structure to get the movement of goods and people ‘out of the mud’. These temporary structures often become permanent with the renowned durability and strength of the Australia hardwoods being tested to the limit.

During the second half of the 20th century the replacement of timber beam road bridges has occurred at such a rate that their current population (excluding a larger number of similar bridges on the railway system) is approximately 4,000. About 110 are under the control of the Roads and Traffic Authority, around 800 are controlled by the State Rail Authority and approximately 3,000 are controlled by Councils.

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Timber Truss Bridges

Study of Relative Heritage Significance of All Timber Truss Road Bridges in NSW

1998

HISTORY OF TIMBER TRUSS BRIDGES IN NSW

1.1 GENERAL

During the first fifty years of the colony of New South Wales, 1788 - 1838, settlement was confined to the narrow coastal strip between the Pacific Ocean and the Great Dividing Range. The scattered communities were well served by ships plying the east coast and its many navigable rivers.

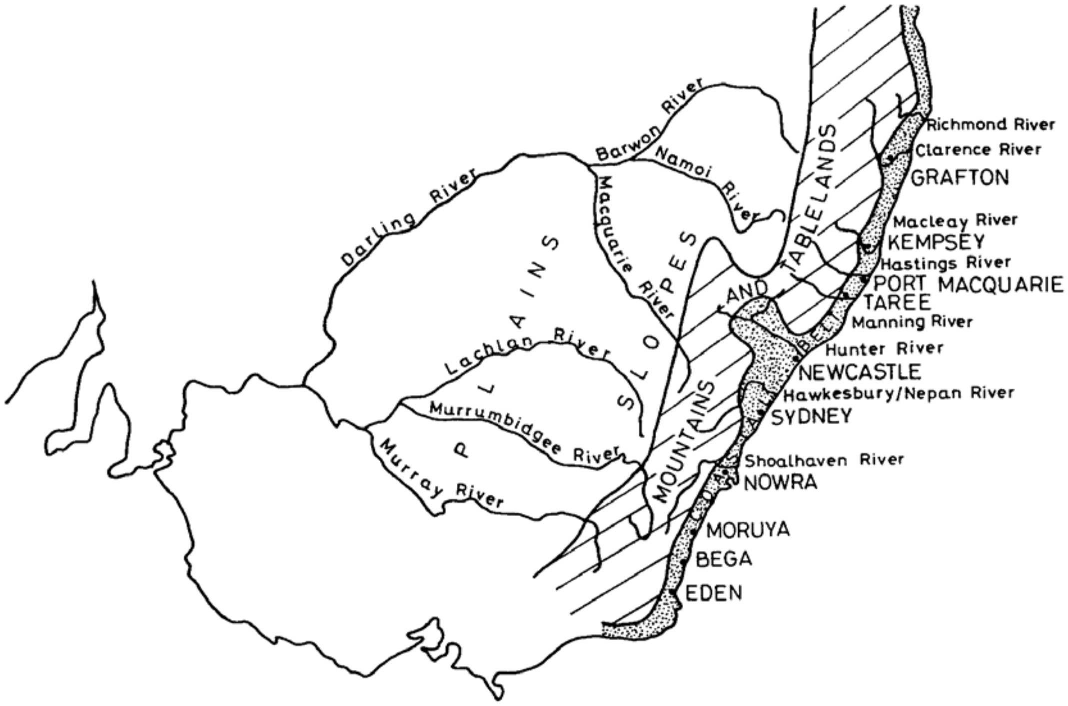


Figure 1.1a: Settlement of early colonial NSW. Shaded areas are settled.

In Governor Macquarie's time between 1810-1822, a number of good roads were built, but despite his efforts and those of the subsequent Governors Darling and Bourke, and of road builders George Evans, William Cox and Thomas Mitchell, the road system and its associated bridges could only be described as primitive. Many roads and bridges were financed through public subscriptions or as private ventures, particularly where tolls could be levied.

The first significant improvement to this situation occurred in late 1832 when Surveyor-General Mitchell observed a competent stone mason working on a wall in front of the Legislative Council Chambers in Macquarie Street. It was David Lennox[R3]. He was appointed Sub-Inspector of Roads on October 1, 1832 then Superintendent of Bridges on June 6, 1833. His first project was to span a gully for the newly formed Mitchell's Pass on the eastern side of the Blue Mountains. This bridge survives in part as a facade concealing a newer concrete structure.

Lennox's crowning achievements are the surviving stone arch bridges at Lansvale over Prospect Creek (opened by Governor Bourke on January 26, 1836) and for Church Street over the Parramatta River (1839). The former carries the heavy northbound traffic of the Hume Highway and the latter carries suburban traffic through the commercial heart of Parramatta. Their permanency, durability and high initial costs were in marked contrast to the more common and less costly timber beam structures. At the time most rivers were crossed at a ford or by a toll-charging punt.

By the 1840s with its economic slump, only the highly priced wool clip could sustain the slow and costly journeys from west of the Great Dividing Range to Sydney.

These were the conditions for land transport in New South Wales prior to the 1850s. Eliminating the worst features of this unsatisfactory situation proved to be a slow process. However, a succession of political, economic, social and technical factors starting in the 1850s, generated a steady flow of improvements.

1.2 HISTORY

History has shown that for progress to take place there must be the simultaneous occurrence of three factors, NEED, KNOWLEDGE and RESOURCES. So it was for the development of bridges in New South Wales over 60 years from 1860 to the 1920s. The principal events of the 1850s are shown in Figure 2.3a.

DATE		EVENT
1850	Aug	Separation of the colony of Victoria
	Oct	Cessation of convict transportation
1851	May	Discovery of gold
1852	June	First timber arch bridge, at Maitland
1853	Aug	First paddle steamer journey on the Murray River
1855	July	Responsible Government granted to New South Wales
	Sept	Railway opened to Parramatta
1856	Jan	First timber truss bridge at Carcoar
	May	First New South Wales Parliament
	Aug	Department of Lands and Public Works created
1857	Mar	First swing bridge, at Pyrmont
		The four Reports of Capt. Martindale on the Internal Communications of the Colony
1859	Oct	Department of Public Works created
	Dec	Separation of the colony of Queensland.

Figure 1.2a: Events

It is not within the brief of this Survey of extant timber truss bridges to elaborate on these events except to say that politics (new colonies, new Parliament), economics (the gold rush, labour shortages), social conditions (the needs identified in Martindale's reports) and technical (the two types of timber bridges) were important factors.

1.2.1 The need for bridges

At the beginning of the second half of the 19th century in colonial New South Wales, the NEED for better road transport had become urgent. Trade and commerce in commodities other than wool was being stifled and goods damaged at the prevailing river fords. Travel generally too was slow, uncomfortable and potentially dangerous, and the movement of people had dramatically increased with the Gold Rushes of the early 1850s. The New South Wales Government also saw a need for a better road system because, beginning in the mid-1850s, a significant amount of its rural wealth was being exported via the inland river system through the rival ports of Melbourne and from Goolwa in South Australia.

Capt. Martindale's reports were published in the Votes and Proceedings of the Legislative Assembly between 1857 and 1860[R4]. In them he draws attention to

> *"the want of bridges suspends inter-communication steep and sliding banks of creeks would be obviated by very ordinary bridges of simple construction"*
>
> *"bridges urgently required at Singleton, Aberdeen, Burrurrundi and Bendemeer"*
>
> *"labour cost are three times those in England"*
>
> *"inhabitants of Gundagai are inconvenienced by creeks along the flats and submergence when the Murrumbidgee floods"*
>
> *"the principles for carrying out road works, first, to bridge the creeks and rivers which habitually stop traffic in times of flood, second, improve the places along the roads."*

These are a sample of the official recognition of the need for bridges and it was also echoed strongly in the newspapers. Petitions for bridges were regularly published, for example,

> "*petition to Sir William Denison includes figures for the stock crossing the Murray River each year, 400,000 sheep, 30,000 cattle & 4,000 horses. Condemnation of ineffective action from centralised governments* "
> (Sydney Morning Herald 1/10/1856)

and community frustration due to lack of building bridges

> *"in the Edwards River District private individuals are prepared to build a bridge at Deniliquin"*
> (Sydney Morning Herald 1/10/1856),
>
> "*city folk don't appreciate the importance of bridges to the interior*"
> (Sydney Morning Herald 14/1/1856)

> "*money spent on bridges is money put to good use*"
> (Newcastle Chronicle 5/7/1870)

followed by expressions of appreciation when bridges were built

> "*as a public convenience, more especially to the residents in the neighbourhood, the Hawick and Russel Street bridges are already much appreciated*"
> (Sydney Morning Herald 11/3/1856)

> "*it would be impossible to describe the intense joy of the inhabitants and travellers generally when they are able to cross the rivers to and fro at any time without hindrance .... it was like a new era*"
> (Anonymous)

> "*bridges present good evidence of the progress of civilization in this country*"
> (Town and Country Journal, April 3, 1880, p648)

and even into the twentieth century the appreciation continued:

> "*several fine new bridges have recently been constructed in inland districts of New South Wales by the Public Works Department ....they will supply a long felt want and give easy communication to people living on both sides of the river*"
> (Town and Country Journal, June 30, 1909, p37)

The NEED had been established early. As for KNOWLEDGE about road and bridge building, it was scarce in the young colony, but there was a substantial body of achievements in Britain and Europe from whence most arrivals had come and among whom there were experienced military engineers and tradesmen. There would be a great deal more engineering and scientific knowledge in the hands of a group of competent bridge engineers in the Public Works Department by the 1890s.

1.2.2 Agriculture and transport

The impact of poor roads and lack of bridges has been indicated in the previous section, and the contemporary evidence is explicit. In his First Report, Capt. Martindale told the Government that

> "in*wet weather rivers are impassable, lives are lost bullock teams make only 3 - 4 miles per day produce rots on the ground for want of transport*"

and in his Fourth Report he

> "*earnestly recommends more Government money for the road program. If improvements stop, dissatisfaction prevails.*"

Punts were not a solution because "*frequently hundreds of teams and horses were waiting to cross*" and the tolls at each of the punts used on a long journey added significantly to the cost per ton-mile.

In the Riverina, the regions was the cheaper bulk transport of the River Trade but this diverted the rural wealth to Melbourne and to Goolwa in South Australia. For the huge area of Western and North-Western New South Wales, access to markets was very poor and settlement on the land was at a low level.

Engineering technology was however about to change all that. The greatest impact came from the railways, particularly once they crossed the Great Dividing Range after 1870. As early as 1855 the developments in timber road bridges were recognised as having long term benefits when, concerning a new bridge over the Belubula River at Carcoar, the Sydney Morning Herald of December 31 remarked

> *"the bridge is on the main road from Bathurst and Western Districts to the Southern Road and will afford the utmost assistance opening up valuable land."*

This did not come to pass until 1861 when Premier Sir John Roberston's Crown Lands Alienation Act provided for free selection of crown lands. New South Wales was gradually transformed from a land of semi-wilderness and large sheep runs into areas of closer settlement including permanent towns and villages.

1.2.3 Rail - road relationship

In the twenty years 1860 to 1880, the adjoining colonies of Queensland, Victoria and South Australia were siphoning off much of the wealth from those border areas of NSW so distant from Sydney. Successive New South Wales governments saw railways as the way to reach those districts and redirect the goods and trade through Sydney. Huge amounts of borrowed capital were invested in the expanding railway network, significant worse for roads and associated bridges was that railway construction absorbed as much as 80% of the Public Works budget[R5]. By the 1880s the political decision had achieved its goals and railways had reached Hay in the Riverina in 1882, Albury in 1883, Bourke in 1885 and Wallangarra in 1888. The fast, all-weather, low-freight-cost railways "killed off" the River Trade and the subsequent spread of branch lines made it possible to economically transport rural produce and opened up the western plains to previously unprofitable crops such as wheat.

The role of the roads was seen to be as feeders to the nearest railway yard where hundreds of men were employed in loading bales of wool and bags of wheat into rail wagons. Even so, the roads had to be suitable for heavily laden drays, particularly in the boggy black-soil country, and the waterways had to be crossed by bridges. The full extent of the branch lines was not achieved until the 1920s so there were large areas between the main railway lines where, given better roads and satisfactory bridges, it was just as easy to use the trunk roads and highways.

The need for road bridges did not decrease despite the dominance of the railways. Instead, the railways generated so much freight and public travel in wide corridors parallel to the early railway lines that roadworks and the construction of bridges proceeded at a pace. In that same twenty years of railway expansion 147 large timber truss road bridges were built together with hundreds more of the smaller span timber beam bridges.

1.2.4 Political landscape for bridges

RESOURCES required were various, with the key element being money. As early as the late 1850s it became obvious that New South Wales was not generating anything like the revenue from gold that Victoria was.[R6] The relative advantage to Victoria was in the order of 4 to 1 and Victoria was only a quarter the size of New South Wales. This meant that the larger colony had to rely more heavily on British capital to pay for its public works programs than did Victoria, with the consequential repayment of large interest bills. New South Wales governments could therefore ill-afford to be lavish with their spending and yet for political and financial reasons they had to ward off the "poachers" on its borders and this required large investments in infrastructure, particularly for railways.

One measure to ease the pressure on the limited financial resources was to avoid labour-intensive masonry arches and to heavily restrict expensive imports such as iron for structural uses, hence the edict of 1861 that local hardwoods were to be used as much as possible. Only John Whitton, Engineer-in-Chief for Railways, had the strength of personality and technical knowledge to defy the edict and build some remarkable, but very expensive railway bridges. The 1863 iron girder bridge at Menangle and the 1867 stone arch viaduct at Picton are still in use. Eventually, however, financial constraints forced him to build many kilometres of timber girder bridges, some laminated timber arches and a few timber truss bridges[R7].

For the Roads and Bridges Branch of the Public Works Department (PWD) there was no such opportunity. Their relatively small budget could not allow for grand designs, so for spans greater than the 35 feet (10 metres) limit of the timber beam bridges they initially, in the 1850s, chose the laminated timber arch which could span up to 90 feet (27 metres). Notable examples were built at Yass, Bathurst, Queanbeyan and Bendemeer. The Bendemeer bridge is shown at Fig 1.2.4a. These structures were difficult to build and proved to have expensive maintenance problems. A better timber bridge was needed and it was the timber truss.

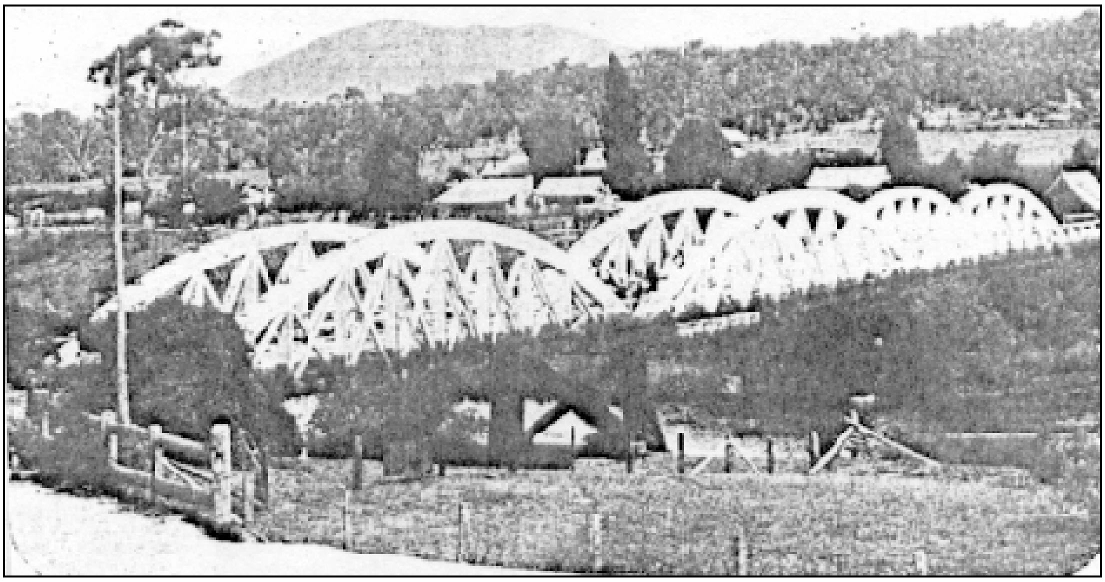


Figure 1.2.4a - 1874 laminated timber arch bridge at Bendemeer.

1.3 THE TIMBER TRUSS BRIDGE, TECHNICAL BACKGROUND AND DESIGN EVOLUTION

1.3.1 Introduction

The evolution of timber truss road bridges in New South Wales from 1860 to 1905 saw a change from traditional, virtually non-scientific, British and European structures to scientifically engineered structures based on developments in America.

Starting in the mid-1850s, the Colonial Architect began to use a European style of timber truss based on the 16th century work of Italian architect Andrea Palladio[R8] with large-span roof trusses. Typical truss details of the 17th and 18th centuries are shown in Figure 1.3.1a. Palladio showed that large roof structures could be assembled economically from relatively small sections of timber. The extension to bridges soon followed. Sketches of some of his trusses are shown in Figure 1.3.1b.

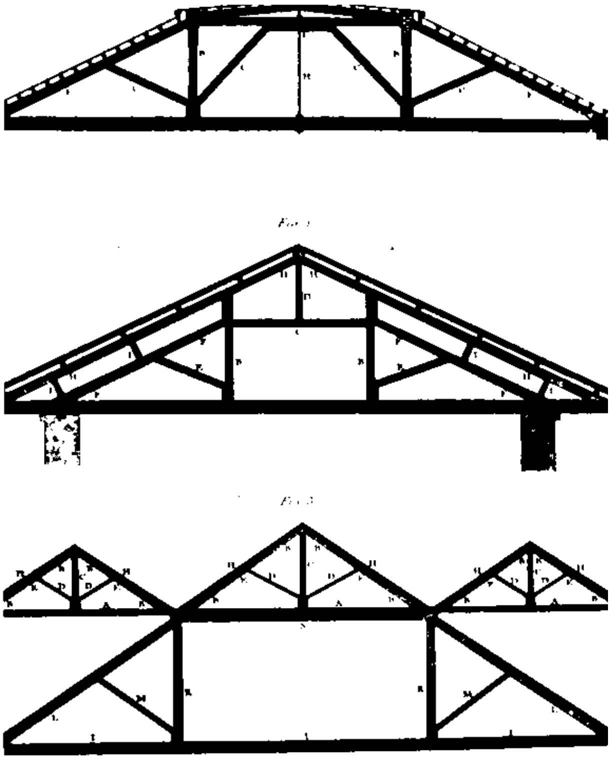


Figure 1.3.1a – 17th & 18th Century roof trusses.

A popular form of roof truss was the Queen Post which eliminated the tall central post of the King Post truss and placed two shorter posts equidistant from the centre which allowed for a horizontal top to the truss as distinct from the apex of a King Post truss. The inner rectangle of the Queen Post truss provided a readily useable space within the roof structure.

When applied to bridges, the Queen Post truss provided a longer shallower profile than a high-peaked King Post truss of the same span and, importantly, inner queen trusses could be incorporated to meet the strength required for longer spans. The Queen Post truss is in fact a simple segmental tied arch, the two sloping end members and the top horizontal providing the compression arch and the bottom horizontal member, being the tie, takes the thrust of the compression arch and holds the segmental arch in place. The combination becomes an internally self-supporting structure that simply rests on piers, trestles or abutments without applying the horizontal thrust at the abutments associated with a traditional arch.

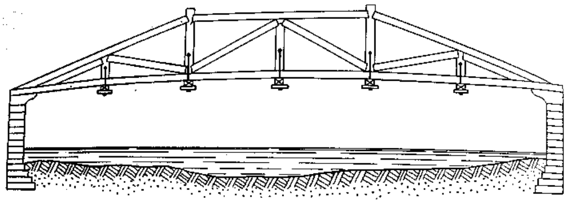


FIG. 117. Palladio's bridge near Trent.

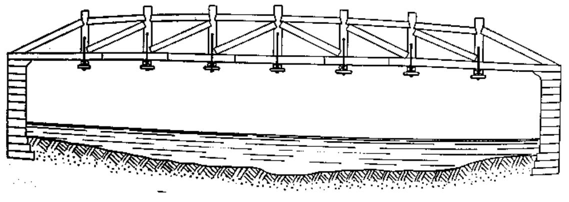
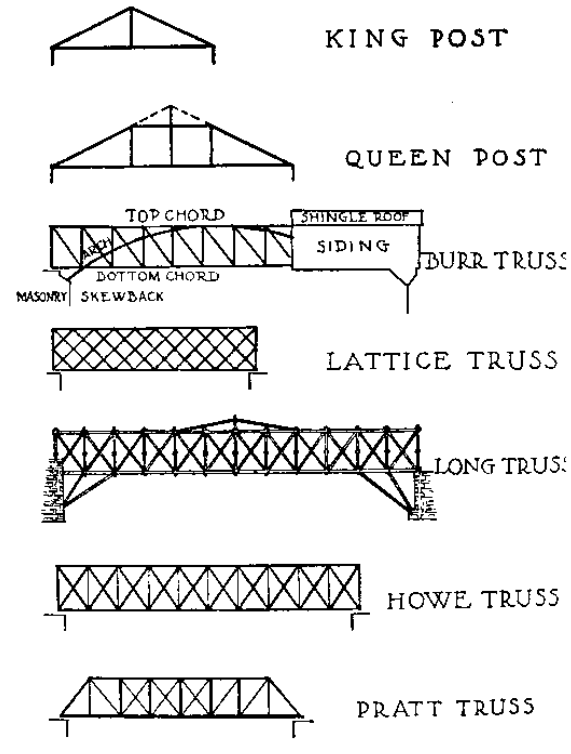


Figure 1.3.1b – Palladio's wooden trusses of the mid 1500's – Timoshenko's History of Strength of Materials page182.

In America, in the 1840s, the indigenous carpenters experimented with and patented many forms of timber truss bridges[R9]. Early examples of their designs are shown in Figure 1.3.1c,d &e. With steady scientific improvements and in-service performances, the two most successful were the Howe and Pratt trusses which, after 1894, became the dominant truss forms in New South Wales both for road and rail bridges.



Types of Timber Trusses

Figure 1.3.1c – Early trusses of the USA.

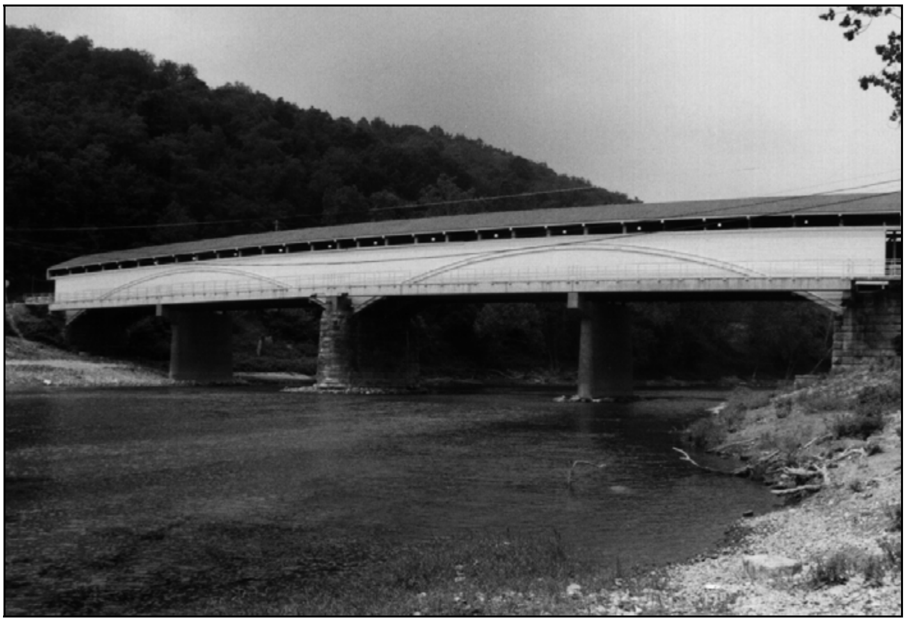


Figure 1.3.1d – Typical American covered timber bridge, the Philippi Bridge, West Virginia

Figure 1.3.1e – A typical Burr truss exposed during restoration work, Barrickville, West Virginia

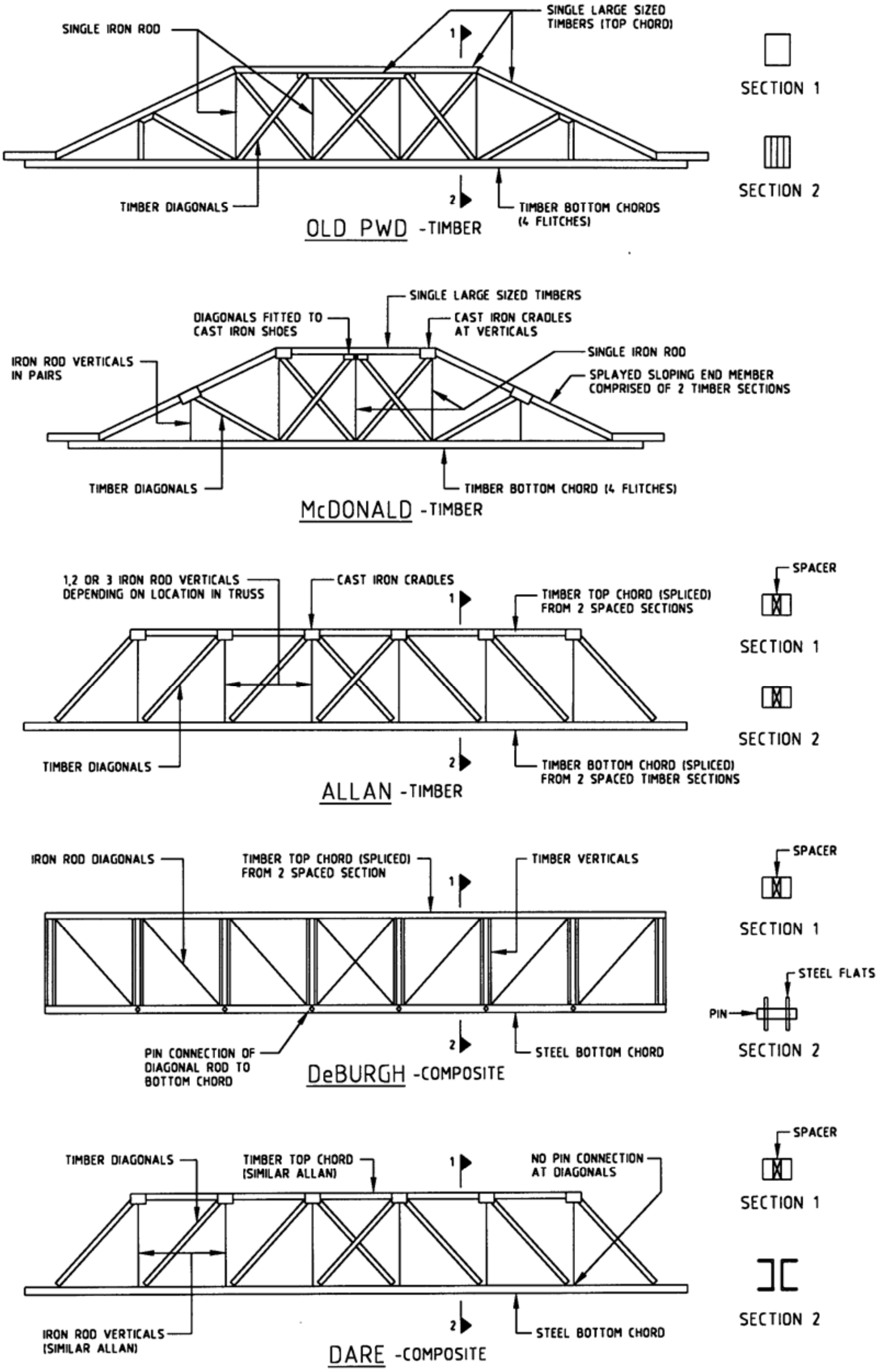


Figure 1.3.1f: Diagrams of truss types used in NSW timber truss road bridges.

1.3.2 The Old PWD Truss

In 1860, Capt. Martindale, shown in Figure 1.3.2a, recorded in his *4th Report on Inland Communications* that there were seven Queen Post truss bridges, with spans ranging from 35 to 68 feet (10 - 21 metres). But it was under William C Bennett, Commissioner for Roads and Bridges (Public Works Department) 1862–1889 (Figure 1.3.2b), that large improvements were made. During his tenure in office and despite the lion's share of the PWD budget going to the railways, he oversaw the construction of 6,000 miles (9,600 kms) of main roads and 4,000 miles (6,400 kms) of other roads and the building of 40 miles of bridges, mostly timber beam bridges and a few iron lattice bridges[R10]. The bridges also included timber truss spans, ranging from 55 to 100 feet, at 147 sites representing an average construction rate of 5 per year. This timber Queen Post truss bridge, so favoured by the PWD from 1860 to 1886, has become known as the OLD PWD truss. A typical truss of this design is shown in Figure 1.3.2c.

Figure 1.3.2a – Captain Benjamin H Martindale.

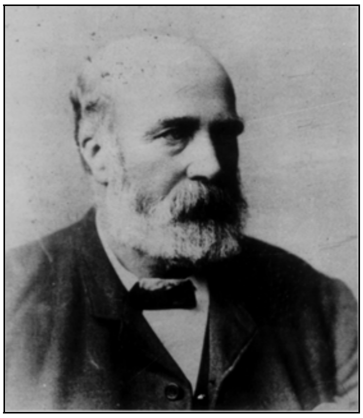


Figure 1.3.2b – William Christopher Bennett, Commissioner for Roads and Bridges (PWD) 1862 – 1889.

Figure 1.3.2c – Typical Old PWD truss
(Monkerai Bridge over the Karuah River)

The benefits to both trade and travel were enormous and the building of bridges, particularly in and near towns, and the subsequent opening ceremonies were regularly reported in the contemporary newspapers and weekly journals. There was less political controversy associated with the roads and bridges program than with the expansion of the railway system. The road network was regarded by successive governments as a feeder network to the nearest railway station or navigable river port. The technical benefits of the OLD PWD truss were limited because there was little engineering science in their design and little practical input into cost-effective maintenance[R11]. Faults were soon recognised, the major ones being as follows:

- the segmental arch components of the truss were all made from single large-sized timbers which were both hard to obtain and difficult to handle and install. Figure 1.3.2d shows a deck view of the Monkerai Bridge over the Karuah River which utilises these large sections.

Figure 1.3.2d - Deck view of the Monkerai Bridge over the Karuah River which has large timber sections typical of the Old PWD design

Figure 1.3.2e – Typical interior view of an Old PWD Truss with an inner truss at mid-span.

- it was extremely difficult to renew such members, particularly the lower inner piece of the top chord in long spans (see Figure 1.3.2e), because taking the defective member out immediately destroyed the structural integrity of the truss so it had to be temporarily supported or even taken out of service until the work was completed. This could impose great inconvenience to road traffic where the next available bridge was many miles away.
- the vertical iron rods connecting the top and bottom horizontal timbers were comprised of single rods installed through the middles of these timbers as shown in

Figure 1.3.2f. Had the theory of structures been applied, it would have shown that loads applied to the rods are larger near the ends of each truss. It is not surprising then that there were frequent breakages of the single rods which seriously weakened the truss span and incurred unexpected and recurring repair costs.

Figure 1.3.2f – View of truss showing single rods all of which are the same size

Figure 1.3.2g –Four flitch bottom chord - View from underside

- the bottom chords were made from four flitches or planks placed side by side on edge and cross bolted together (see Figure 1.3.2g). This was equivalent to vertical rather than the horizontal laminations applied at the earlier arch bridges. The same flaw existed for each arrangement of laminates, in that when the inner laminates deteriorated, it was extremely difficult to renew them and a completely new assembly of flitches was required.

- shrinkage of the local hardwoods caused joints to open up such that the truss developed excessive sag or deflection. Packing at the bottom chord joint as shown in Figure 1.3.2h alleviated the problem but required regular adjustments as the shrinkage continued over many years.

Figure 1.3.2h – Packing at bottom chord was used to help counter the effects of shrinkage.

Consequently, although the 147 OLD PWD truss bridges served their function well, with their average life being 54 years with 26 in service from 80 to 117 years, they were both expensive to build and maintain. There was scope for improvement.

1.3.3 The McDonald Truss

Throughout this period, the engineers who progressively joined the Public Works Department were mostly expatriate Britishers or Europeans and consequently, infrastructure design was dominated by British or European technology. When John A McDonald joined the Department in 1879 he was one of the first bridge design specialists and was to become Engineer for Bridges from 1889 to 1893. Almost immediately after joining the Department he set about designing a new timber truss bridge that would be easier to build and maintain and which could carry loads significantly greater than the OLD PWD designs, in order to provide some allowance for future increases in vehicle loads. The design has become known as the McDONALD TRUSS, following Percy Allan's 1924 reference to the "McDonald style" truss. Figure 1.3.3a is of the Junction Bridge at Tumut, typical of McDonald's design.

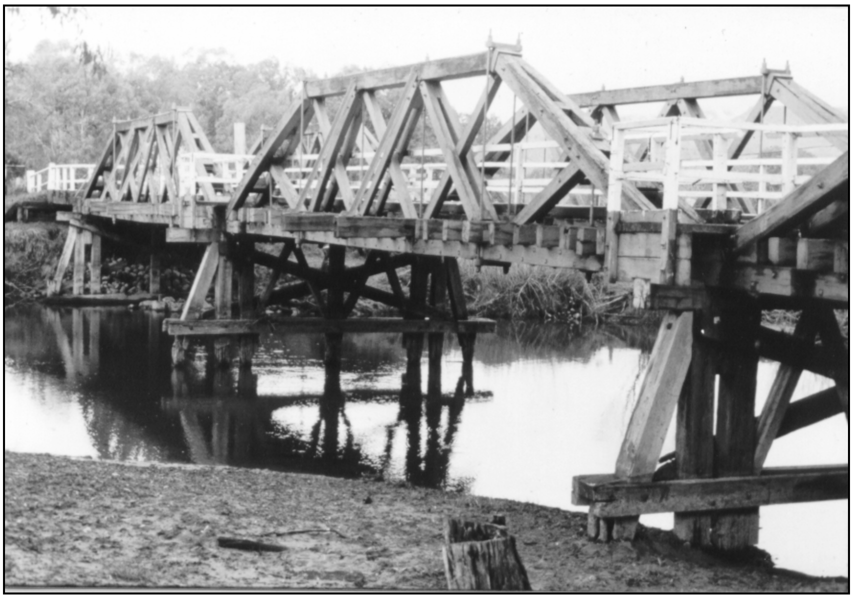


Figure 1.3.3a – McDonald Truss - Junction Bridge at Tumut remains in use to this day.

McDonald's design was still based on the European type of bridge truss so they look similar to the OLD PWD trusses, but there were important technical improvements, such as:

- elimination of the double thickness top chord for the longer span trusses (see Figure 1.3.3b).

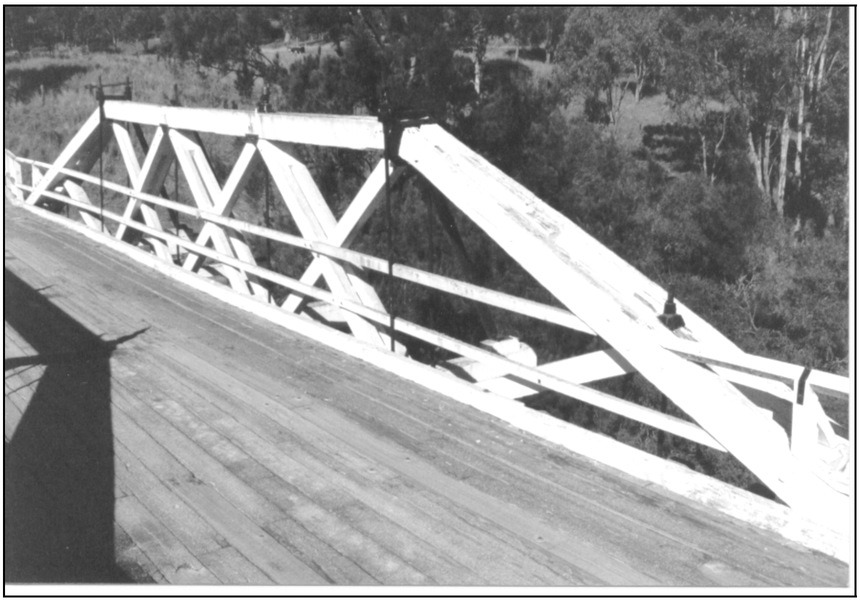


Figure 1.3.3b – The single thickness top chord was part of McDonald's improvement to the OLD PWD trusses.

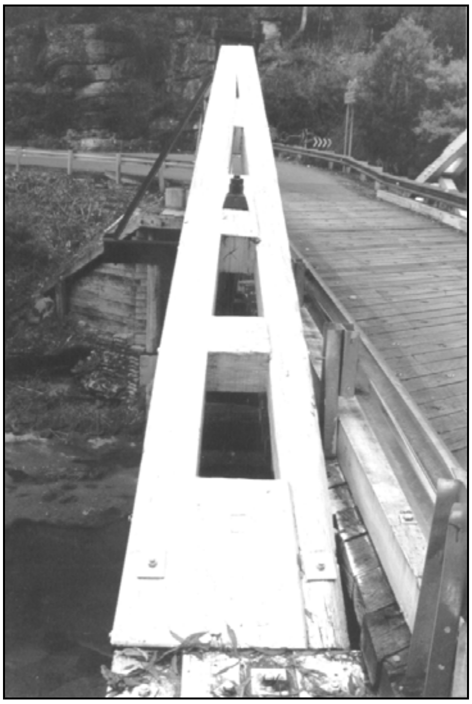


Figure 1.3.3c – Splayed end members increased the stability of the truss.

- the splaying of the sloping end member so as to increase stability of the compression top chord which was prone to buckling. (Figure 1.3.3c)

- the vertical rods at the ends of the his trusses were placed outside the chord timbers and held in place by cast iron cradles as in Figure 2.3.3d. This eliminated the need to drill through the chord members so the number of rods was doubled and larger sizes could be easily incorporated and kept tight.

Figure 1.3.3d – Vertical rods placed outside the truss faces eliminated the need to drill through the top chord.

Figure 1.3.3e – Connection of diagonals to top chord via cast iron plates provided a superior transfer of force.

- the diagonal timbers were fitted into cast iron plates (refer Figure 1.3.3e) at their junctions with the top chord timbers so as to give good force transfer at the joints.

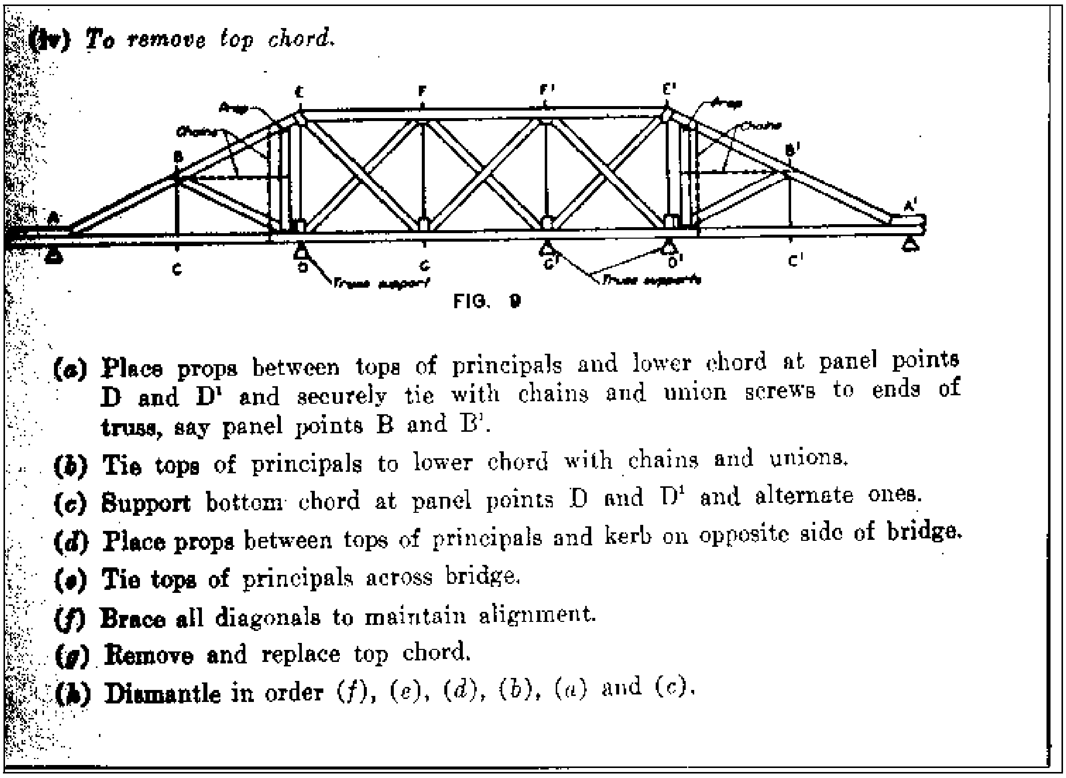
- where the diagonal timbers met the bottom chord joints, opposing steel "fox" wedges were installed (see Figure 1.3.3f) so that regular hammering would keep the shrinkage gap filled, thereby reducing long-term deflections.

- methods were devised whereby combinations of chains and a minimum of temporary timber supports (see Figure 1.3.3g) could be used to create an alternate internal load path thereby relieving a defective timber of load. This allowed its easy removal and replacement without taking the bridge out of service and with little interference to traffic. After WWII the Bailey bridge largely superseded these methods of temporary support, see Figure 1.3.3h.

- the use of sawn timber from heartwood which was of similar quality to the hewn timber, was less costly and more readily available.

McDonald's crowning achievement, however, was his pioneering of the new technology of composite trusses where timber and steel were used to their best purposes. The bulky and relatively lower-strength timbers were best suited to members in compression, hence the top chord, end sloping members and the diagonals were timber members. The higher strength of steel made it more suitable for slender tension members, the verticals and the bottom chord. In his design for the 3-spans trusses over the Lachlan River at Cowra in 1893 he demonstrated the potential for composite construction with a span of 160 feet, almost double the previous longest span of 100 feet. The bridge served 93 years and was replaced in 1986. One span was saved and is on display in a nearby riverside park (see Figure 1.3.3i). Note that typical McDonald trusses had timber bottom chords.

Figure 1.3.3f – Steel fox wedges were used to counter shrinkage effects and provided a simple means for regular adjustments.



(iv) ***To remove top chord.***

FIG. 9

- **(a) Place props** between tops of principals and lower chord at panel points **D and D^1** and securely tie with chains and union screws to ends of **truss,** say panel points B and B^1.
- **(b) Tie tops** of principals to lower chord with chains and unions.
- **(c) Support** bottom chord at panel points D and D^1 and alternate ones.
- **(d) Place props** between tops of principals and kerb on opposite side of **bridge.**
- **(e) Tie tops of** principals across bridge.
- **(f) Brace all diagonals** to maintain alignment.
- **(g) Remove** and replace top chord.
- **(h) Dismantle** in order (*f*), (*e*), (*d*), (*b*), (*a*) and (*c*).

Figure 1.3.3g – Removal of top chord was made possible with the creation of alternative temporary load paths.

Figure 1.3.3h – Bailey Bridges became the preferred method of temporary support during maintenance and rectification works.

Figure 1.3.3i – A span of the original Lachlan River Bridge at Cowra on display at a nearby riverside park. The bridge utilised steel tension members and timber compression members in an early example of composite design.

In the short period, 1886 - 1893, McDonald truss bridges were built at 91 sites at an average rate of 13 per year, a remarkably productive though short-lived boom despite the onset of a severe economic depression.

1.3.4 The Allan Truss

In 1890, as the economic depression began to grip New South Wales, the 29-year old chief draftsman and engineer, Percy Allan[R12] (see Figure 1.3.4a), began a complete revision of the timber truss bridge to incorporate the proper engineering science of the structural behaviour of trusses, and to use the reliable strength data of Australian hardwoods obtained from Professor Warren's testing program at Sydney University in order to reduce the costs of construction and maintenance.

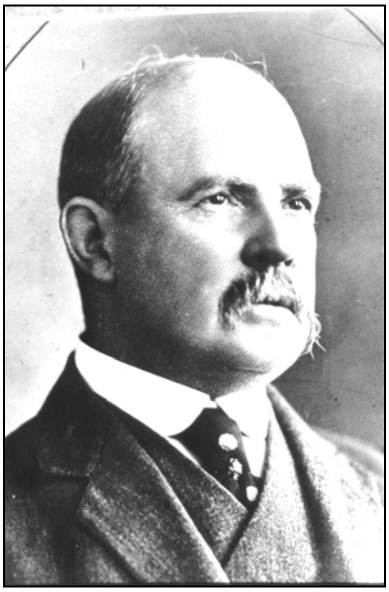


Figure 1.3.4a - Percy Allan.

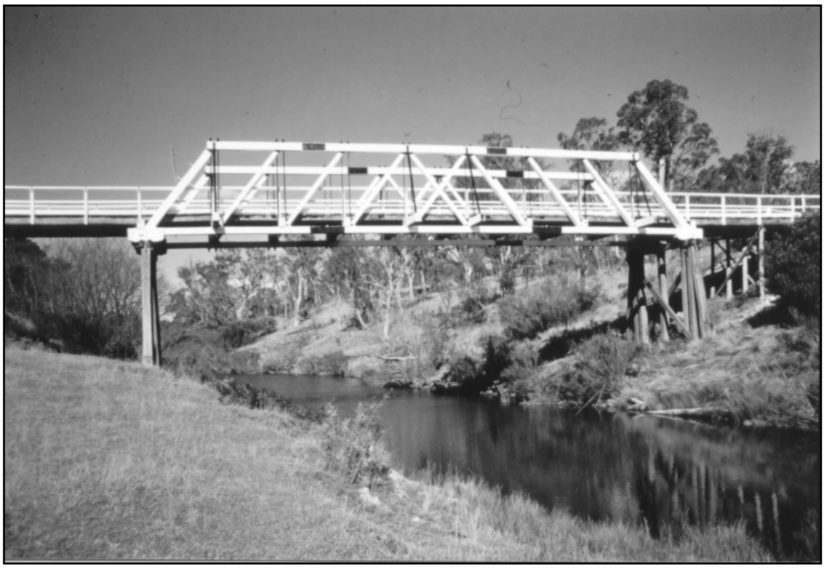


Figure 1.3.4b – The simple lines of a typical Allan truss.

In 1893 Allan introduced his new design based on the American Howe truss (see Figure 1.3.4b). It was not however, a composite truss as foreshadowed by McDonald because only the verticals were iron rods while the bottom chord, despite being a tension member, was still all timber. The new truss featured a much simpler arrangement of triangulations and incorporated many improvements and innovations, derived from his design and practical experience, that made this truss a more cost-effective structure than its predecessors. The PWD Annual Report for 1893-94 had these comments,

> "*The type of design for truss bridges in use since 1884 has been superseded by a truss of more modern design, the principal features of which are: the use of marketable lengths of timber, the adoption of open chords and braces always accessible to the brush, and the ease with which any defective timber can be replaced.*"
>
> *"In each of the new 90-feet spans there is a saving of 450 cubic feet of timber and it carries 10 feet more roadway than the old truss. There is also a saving in effort owing to the shorter lengths of timber employed and the greater ease of framing. Altogether the saving is on the average 20 per cent."*
>
> *"The introduction of the large timber truss adopted at Wagga Wagga will now permit the economical bridging of those rivers which cost had hitherto rendered prohibitory."*

Then in the next Annual Report it is stated that

> *"One of the most important matters in connection with the work done has been the introduction of the new form of truss which is proving to be cheaper in construction and promises to lessen the cost of maintenance."*

Figure 1.3.4c – Parallel pairs of members held apart by timber spacers were used to improve load characteristics, aid painting and prevent the collection of water.

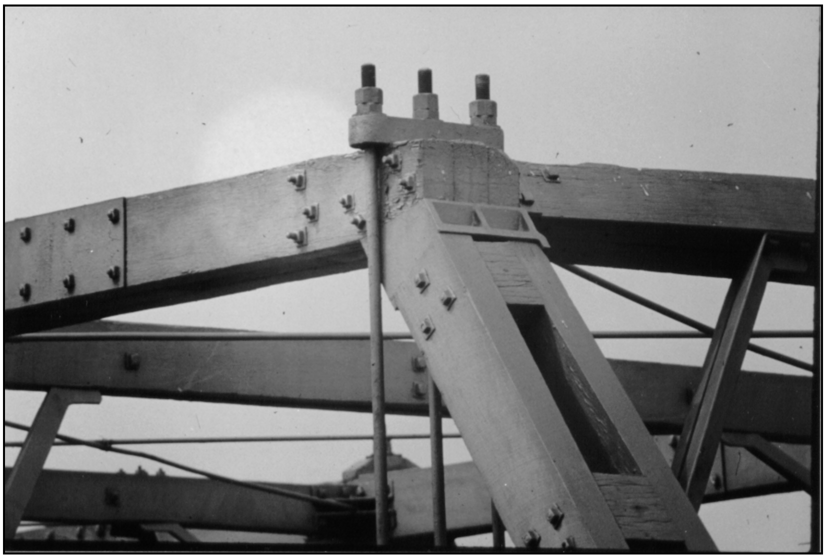


Figure 1.3.4d – The simple truss shape allows tightening via the nuts on the top chord to combat shrinkage effects. One, two, or even three vertical rods were possible due to the separated members. The cast iron shoes allowed good transfer of forces at truss joints.

This timber truss, which could carry 50% more load but with 20% less material, has become known as the ALLAN TRUSS. Allan designed three sizes, the 70 and 90 feet spans in the conventional "pony or half-through" style and the 110 feet spans which were "through" trusses, tall enough to accommodate horizontal sway bracing above the traffic.

In his 1924 series of papers[R13], Percy Allan summarised the important aspects of his achievement as:

- all timber members were assembled from relatively smaller and shorter sizes, spliced at regular intervals for the top and bottom chords, laid parallel in pairs but held apart by spacer timber blocks. This allowed rain water to fall through, gave easy access for painting and for the compression members it increased their buckling strengths (see Figure 1.3.4c).

- external iron clamps at the joints meant that the vertical rods could be placed within the space between the top and bottom chord timbers or outside these members. One, two or three vertical rods could be accommodated depending on the magnitude of the shear force at the member (see Figure 1.3.4d).

- cast-iron shoes at all joints ensured proper truss action and a good transfer of member forces at the joints (see Figure 1.3.4d).
- the simple triangulations, mostly without crossed diagonals allowed the truss to be kept tight simply by applying large spanners to the nuts at the vertical rods along the top chord (see Figure 1.3.4d).

- any member could be renewed without temporary staging from below and without taking the bridge out of service.

- These above are improvements in the details of construction and maintenance, but Allan's REAL INNOVATION was the concept of building two parallel half trusses and bolting them together to form a complete truss, one on each side of the deck. Member replacements in effect only involved half members, making repairs easier and quicker to do, and yet enough of the structural integrity of the truss was retained to keep the spans in use.

Figure 1.3.4e – Hampden Bridge, Wagga Wagga.
The first of Allan's large overhead through truss bridges
with 3 truss spans, each of 110ft (33.5m).

Figure 1.3.4f – Morpeth Bridge. The oldest serving over head timber truss bridge recently celebrated its centenary (opened 1898).

The immediate success of Percy Allan's design was good news for colonial governments of the late 1890s wrestling with the financial, social and unemployment consequences of the economic depression. The improved economics of Allan's design assisted Governments in implementing public works programs to both relieve unemployment and achieve more infrastructure for the meagre funds available. The rate of construction was, however, not as intense as for the McDonald period.

The transition year was 1894 with the last of the McDonald truss bridges and the first of the Allan truss bridges being completed. The latter was over Glennies Creek at Camberwell just north of Singleton, opened for traffic on 13 August 1894. The first of the large overhead-braced truss bridges was built a year later over the Murrumbidgee River at Wagga Wagga, comprised of three 110 feet spans and opened for traffic on 11 November 1895 (see Figure 1.3.4e). In 1998 it was extant but out of service. The largest of these projects was over the Macleay River at Kempsey where four 154 feet spans were opened for traffic on 5 April 1900. This bridge was replaced by steel trusses in 1959. Currently, the oldest serving large trusses are those at Morpeth opened on 15 June 1898 (see Figure 1.3.4f).

13.5 The DeBurgh Truss

The technical merits of composite construction, utilising timber for compression and steel for tension, and pioneered by J A McDonald in 1893 at Cowra were not lost on the brilliant team of engineers in the PWD at the end of the colonial era. They included the senior engineer E M DeBurgh[R14] (see Figure 1.3.5a) and three young top graduates from Sydney University, Harvey Dare, J J C Bradfield and J W Roberts.

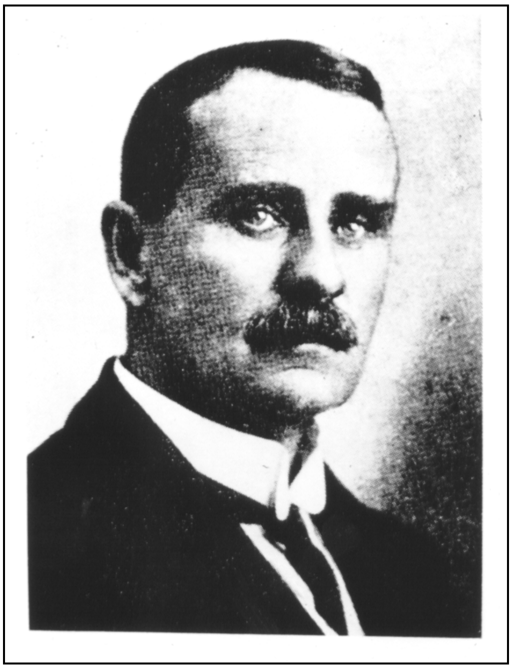


Figure 1.3.5a – Ernest M. DeBurgh

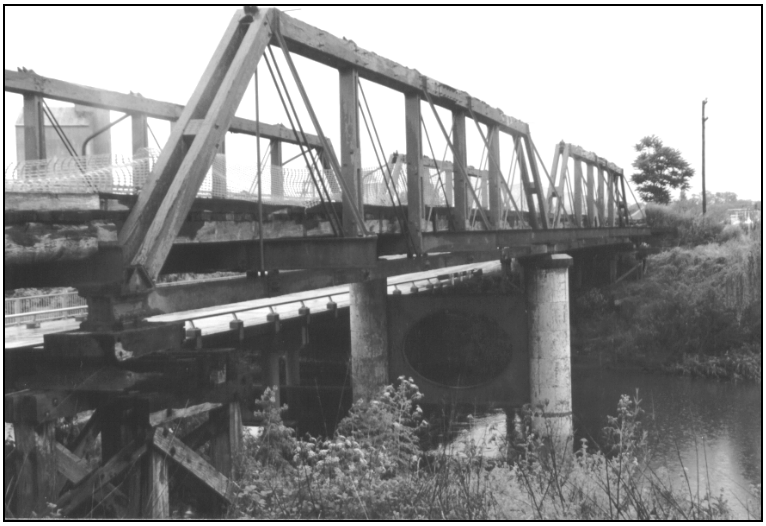


Figure 1.3.5b – The bridge over the MacIntyre River at Inverell was one of DeBurgh's early Pratt trusses with sloping end members.

Ernest McCartney DeBurgh was among the last of the expatriate British engineers of the colonial period having joined the PWD in 1885 and he was involved in both the design and construction of bridges. His first composite truss bridge was built over the Queanbeyan River at Queanbeyan. It replaced the 1878 OLD PWD truss bridge known as the Queens Bridge, and was opened on 16 March 1900. The Annual Report to 30 June 1899 stated

> *"This bridge is rapidly nearing completion and is of considerable interest because the Pratt style of truss, with vertical posts and inclined tension members, has been adopted in lieu of the Howe type. The superiority of steel over timber in tension, and the great cost of replacing the timber chords, points to a great economy in maintenance."*

Percy Allan, in his 1924 series of papers added that

> "*the bottom chords are of steel and are connected to the diagonal rods by turned pins."*

This first composite Pratt truss bridge was replaced by a prestressed concrete structure in 1975 but an example of its type with sloping ends is extant over the MacIntyre River at Inverell (see Figure 1.3.5b). It provided access to the railway yard nearby but is out of service next to a new concrete bridge.

Figure 1.3.5c – The square ends that are typical of the DeBurgh truss.

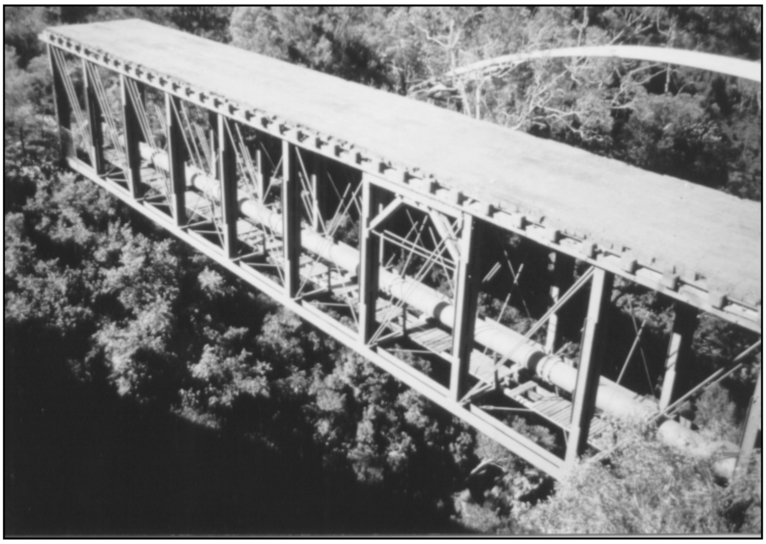


Figure 1.3.5d – The 1901 DeBurgh Bridge over Lane Cove River. DeBurgh's greatest achievement with a 165ft (50.3m) deck span was damaged in the 1994 bush fires.

A minor technical change was subsequently made whereby the sloping end members were replaced by a conventional rectangular Pratt panel. Henceforth all DeBurgh trusses have had the familiar squared ends (see Figure 1.3.5c). In 1998 there are nine of these bridges in service. His greatest achievement was the 165 feet deck span over the Lane Cove River on the North Ryde to Gordon Road pictured in Figure 1.3.5d. It was opened on 20 December 1900 and officially named the DeBurgh Bridge on 23 February 1901. Unfortunately it was destroyed by the bush fires of January 1994.

Figure 1.3.5e – Pins along the bottom chord facilitated speedier construction but later lost favour due to the difficulties experienced in maintenance and strengthening works.

DeBurgh incorporated all the improved features of Percy Allan's revision but changed some details to suit the inclusion of the steel bottom chord. The overall result was a stiffer, structurally superior truss for which member replacement was quite easy. However, the inclusion of pins (see Figure 1.3.5e) along the bottom steel chord was a carry-over of the American system which, although it allowed rapid construction, was a hinderance to certain aspects of maintenance and future strengthening. Local engineers were aware of this through experience with the 1889 Hawkesbury River railway bridge. Consequently, the DeBurgh trusses were only constructed for the relatively short period between 1900 and 1905.

13.6 The Dare Truss

This was the most successful composite truss, having a construction period from 1905 to 1936. In 1903 the 36-year old bridge designer, Harvey Dare, was in charge of highway bridge design and took the opportunity to change the composite truss. He returned to the Howe truss arrangement of the Allan truss but substituted a pair of steel channels for the timber bottom chord (see Figures 1.3.6a & b) and redesigned the bottom chord joints to eliminate the pins of the DeBurgh truss. He achieved further simplicity in member replacements thereby creating the most cost-effective timber truss, at the end of this evolutionary process. The Dare truss bridges have the highest survival rate, 24 are extant in 1998 of the 44 built. In fact the first one, completed in 1905, is extant over the MacDonald River at Bendemeer being used as a footbridge.

Figure 1.3.6a – Bulga Bridge over Wollombi Brook is typical of Dare's design.

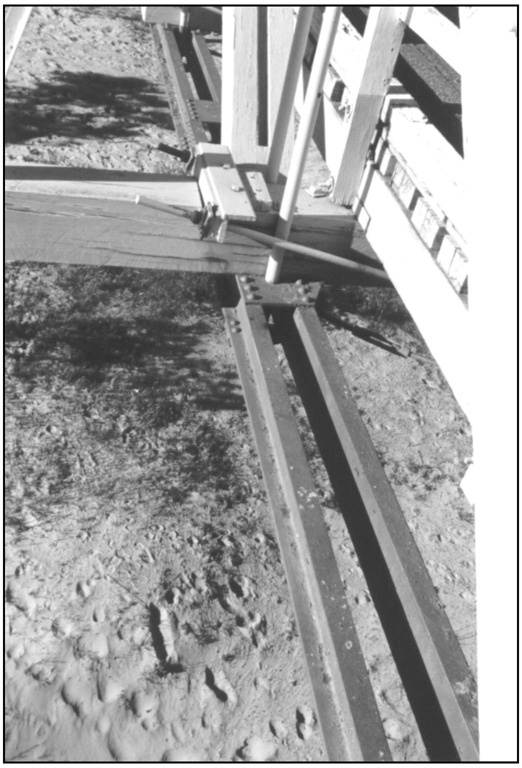


Figure 1.3.6b – The pair of steel channels that made up the bottom chord utilised the tension characteristics of steel along with the compression characteristics of the timber.

1.3.7 Summary

The timber truss, from the OLD PWD (1861) to the DARE (1936), was the mainstay of large span bridge construction in New South Wales for 60 years until, in the 1920s when the BHP steelworks at Newcastle began to supply steel to the local market and reinforced concrete became the new technology for road bridges.

There were in excess of 400 timber truss bridges built in NSW, as shown on the following distribution table, whereas other colonies and states did no better than 10% of this figure or even none. Travellers into New South Wales dubbed it the "timber bridge State".

Unfortunately, these bridges had a number of faults:

- they were designed for loads much less than those applied by modern heavy trucks;
- they were built as single lane bridges, an inconvenience to modern traffic densities;
- the decking, cross girders and timber bottom chords were designed for traffic travelling much slower than today, so impact and fatigue effects are greater. But the new technology of Stress Laminated Timber decks is showing encouraging signs of prolonging the lives of the surviving timber truss bridges;
- water has been the greatest scourge, despite Percy Allan's details designed to shed as much water as possible, and has led to considerable rotting of the timbers. Fortunately, many timber members are being protected by metal sheeting and there are cost-effective chemical treatments now that suitable available hardwood pieces have become progressively more difficult to purchase;
- maintenance costs, particularly for the three all-timber truss types, have continued to be relatively high because much of the work is labour intensive.

All of these factors were mentioned at various times in the PWD Annual Reports as early as around 1900. Despite the many new timber truss bridges built during the first twenty years of this century, replacements in steel and concrete has produced a steady decline in the population of timber truss bridges. No timber truss bridges have been constructed since 1936. It has been possible to monitor the decline since 1940 and this is shown in the Figure 1.4b.

The situation has been reached in 1998 where the surviving 82 represent only 19% of the total constructed and it is likely to be lower by the year 2000 as some new bridges come into use and the old timber trusses are demolished.

Pre-1930 Metal Bridges

Study of the Heritage Significance of Pre-1930 RTA Controlled Metal Road Bridges in NSW

1998

HISTORY OF METAL ROAD BRIDGES IN NSW

1.1 Historical Review

The chronological list of metal bridges supplied with the Brief provides a convenient framework for this historical review for which there are the following principal papers:

- *The First 60 Years of Metal Bridges in New South Wales* (Fraser D.J. 1986);
- *Moveable Span Bridges in New South Wales prior to 1915* (Fraser D.J. 1985);
- *Curved-tracked Bascule Bridges in New South Wales and their relationship to the Cardioid* (M A B Deakin and D. J. Fraser 1995);
- *The Roadmakers* (Department of Main Roads New South Wales 1976);
- *Bridge Building in New South Wales 1788-1938* (Department of Main Roads New South Wales);
- *All About Bridges* (Department of Main Roads New South Wales 1970);
- issues of *Main Roads* (Department of Main Roads New South Wales);
- *Highway Bridge Construction. The Practice in New South Wales* 1924 six-part series (Percy Allan 1924).

Other references are cited where they are relevant.

However, the supplied list does not indicate what type of bridge each entry is (arch, truss, girder/beam or moveable span), nor the material used (cast iron (CI), wrought iron (WI) or steel). This limits the ability of the list to convey a historical overview or to give any evidence of trends in the use of each type of bridge. This is shown in Table 3.1 below.

Table 3.1

Types, Materials and Eras of the Bridges

Arches	1		1889	CI
Trusses	27		1865 – 1930	WI then steel
Including:	14	Lattice Trusses	1874 – 1893	WI
Girders and Beams	16	Plate Web and Rolled	1867 – 1928	WI then steel
Moveable	7		1888 – 1906	WI then steel
Including:	4	Lift	1888	WI
	1	Swing	1903	Steel
	2	Bascule	1905 – 1906	Steel

The Albury arch

Typical lattice truss

Overhead braced truss

Nepean girder, Penrith

Steel beams at Wallarah Creek

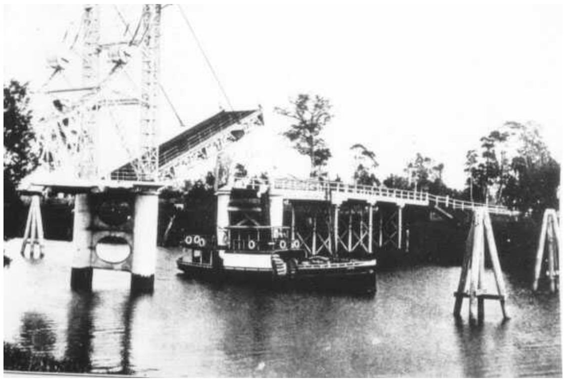
Lift bridge at Brewarrina

An example of the different types of metal bridges.

In addition to the principal 51 bridges, the RTA supplied details of 32 similar metal bridges, under the control of other agencies such as the Rail Access Corporation and local councils, which are for comparative purposes in assessing the heritage rankings of the 51 bridges. These other bridges are included, where relevant, in the historical review.

This review is not simply a presentation of dates and technical facts, it is a component of a broader history in which politics, economics, social inputs, personalities and technical innovations are just as important as the technical history, and more so on occasion.

Glebe Island swing bridge



Bascule bridge at Coraki

For example, the most common form of road bridge in colonial New South Wales was the timber beam bridge (Cardno MBK 2000). Based on the availability of high quality local hardwoods, such as ironbark, these bridges were cheap and easy to build. Although their long-term maintenance costs were to prove high, they became the foundation bridge structure for the developing network of roads (and railways) and by 1900 represented 87% of the road bridge population (PWD Annual Reports). Timber truss bridges, in contrast, comprised approximately 10%.

The cause for this dominance of timber was formalised by government decree in 1861 when the enormous costs of John Whitton's imported wrought iron railway bridges at Menangle, Penrith and Goulburn had the potential to bankrupt the fragile economy of New South Wales. Only metal bridges with essential technical merits were approved and only during the boom years of the 1880s was there a significant use of major metal bridges, particularly the lattice trusses. The depression of the early 1890s further restricted the use of metal bridges until the economic recovery began around 1895 by which time steel, also an expensive import, had displaced wrought iron.

Despite the establishment of a steelworks at Lithgow in 1908 followed by the BHP steelworks at Newcastle in 1916, local production did not begin to meet local needs until the mid-1920s. In the case of the railways, an extensive programme of brick arches compensated for the limited supply of steel for bridge construction.

Consequently, there was a general lack of locally produced wrought iron and then steel up to about 1930. Typically, steel for the 1929 Tom Ugly's Bridge over the Georges River at Sylvania was supplied by Cargo Fleet, England. But then, metal road bridges in the 60 years from 1867 to 1927 were a very small percentage of the total population of road bridges, even though they dominated the major bridges. For most of this time, the Annual Reports of the Department of Public Works indicated a bridge population steadily increasing to around 4,000 with metal bridges accounting for less than 3%.

Dorman Long (England)

Cargo Fleet (England)

Shelton (England)

Hallside (England)

On 1 January 1907 the Local Government (Consolidation) Bill came into operation whereby an administrative system of Municipal and Shire Councils came into being. The councils were to be responsible for a wide range of local activities hitherto managed by the previous colonial governments and the recent State governments. Councils could finance these activities by levying rates on the populations (ratepayers) and properties within their boundaries. But it was recognised that councils could not generate enough income to fund expensive works programmes previously carried out by the PWD (1906-07 Annual Report).

Therefore, in the 1906-07 PWD Annual Report under local government there appeared the following:

> *In accordance with the Provisions of the Act a number of bridges have been declared to be national works, and so exempted from the control of the councils. Only such works as, by reason of their size, cost, and extra-local importance, are such as the local councils cannot reasonably be expected to maintain, have been declared to be "national".*

Two schedules were published in the Government Gazettes of 31 December 1906 and 27 March 1907 proclaiming the listed bridges to be National Works. These lists included such bridges as Vale Creek, Perthville; Murrumbidgee River, Gundagai; Shoalhaven River, Nowra; Hunter River, Luskintyre; Orara River, Bawden; Nepean River, Penrith; Bungambrawatha Creek, Albury; A'Beckett's Creek, Parramatta; the bascule bridges at Coraki and Maclean, and so on.

A total of 258 bridges were listed to be National Works, including timber truss bridges and some iron beam bridges. Most of the older metal bridges reviewed in Section 4 were so proclaimed, which attests to their size, importance and significance.

Therefore, the bridges in this study represent a very significant group of survivors in terms of heritage significance.

1.2 Deck, Half-Through and Through Bridges

These are important technical terms about bridges because they relate to the appearance of bridges and how they carry their loads to their supports. All three categories are represented in the bridges in this study. The simplest definitions are:

- **Deck bridges** have the whole of their superstructures below the level of the deck, that is, the deck sits on top of the bridge.

Beam bridge at Oxley

Manilla lattice truss approach

Two examples of deck bridges: beam and lattice truss.

- **Half-through bridges** have a cross-section that is U-shaped. The deck spans between the bottom levels of the supporting superstructure and traffic passes between or through a shallow depth bridge.

Note that the top of the superstructure is open so that nothing joins the tops of the side bridging elements (it would be a barrier to traffic), hence the term half-through bridge.

A piece of bridge vernacular, occasionally used in Australia, is the American term “pony bridge” or “pony truss” for the half-through bridge, because it is too small to have overhead bracing like a “fully grown” bridge.

Girder bridge, Penrith *Bawden lattice bridge*

Typical half-through bridges.

- **Through bridges** are usually taller trusses having bracing between the tops of bridging elements such that the traffic drives through the bridge like a spatial tunnel.

The Luskintyre trusses are a good example of a through bridge.

It is worth noting that for pre-1930 bridges in New South Wales:

- Beam bridges, old or recent, are usually deck bridges;
- Girders (beams which are fabricated because they are deeper than "off the shelf" rolled steel beams and can range from one to three metres deep) and trusses of modest depth (the lattice trusses), during the second half of the nineteenth century, usually made half-through bridges. However, such bridges have a degree of structural inefficiency and eventually reach their limits of application;
- Then in the first quarter of the 20th century, with better structural design and the steady increase in the spans of bridges, the taller through truss began a dominance that lasted another 50 years.

1.3 Iron and Steel Trusses with Overhead Bracing

In Section 3.2 attention was drawn to three types of trusses and the illustrations of them. They were the deck truss (wholly beneath the traffic), the half-through or "pony" truss (the traffic drives between the trusses and large vehicles are taller than the trusses) and the through truss (trusses tall enough to be cross-braced overhead, above the tall vehicles, such that all traffic drives through the bridge like a spatial tunnel).

The approach spans to the 1886 Manilla bridge (No3655) are examples of deck trusses; the family of colonial lattice bridges exemplify the half-through or "pony" truss; and the 1881 Whipple trusses at Nowra (No 713) are through trusses. The first example of a post-colonial through truss is at Luskintyre, in the Hunter Valley, so a brief explanation of its development follows.

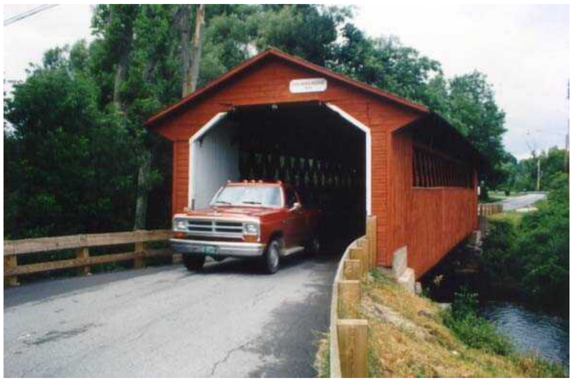
The development of through trusses was essentially an American innovation. Although some early examples appeared in Britain and Europe, bridges in the Old World were dominated by the half-through bridges, girders and trusses. Even when overhead bracing was used, it was generally applied to a half-through structure as shown in the two photographs below.

European style half-through bridge with overhead bracing at Bathurst

1914 Goodiwindi trusses, axis view

Through bridge construction began with the American covered bridges as early as the 1840s. There were various types of patented timber truss configurations but all were tall enough to be completely enclosed by a protective "skin" of timber boards along the sides plus a roof. The unlit interior really did make driving feel like being inside a tunnel, truly a through bridge.

The American iron industry grew rapidly from the 1860s and metal bridges, particularly those used for the heavier railway loads, began to replace timber bridges and were usually the first choice for new lines. Many of the metal bridges were half-through, particularly for girder bridges where span limitations automatically meant girders of shallow depth, without requiring overhead bracing.



One American enclosed through bridge was the covered timber bridge which became an open spatial arrangement in metal.

Early American through truss

Steam loco and train on half-through girder bridge

As the spans of bridges increased, the metal truss quickly emerged as the ideal structure. The greater the span, the deeper (taller) the side trusses, and very soon through construction from the covered timber bridges became standard. With the inclusion of pinned joints (see photographs of the Nowra Bridge deck in Section 4.7) and the change over from iron to steel around 1880, the large pin-jointed steel truss came to symbolise American bridge technology.

A new generation of engineers educated at Sydney University, J J C Bradfield and Harvey Dare to cite just two, were well aware of the technical merits of American trusses but it was not until the retirement of long serving Chief Engineers John Whitton (Railways) and William Bennett (PWD) that American bridge technology took hold in New South Wales. Following their successful use in 1894 on the Lismore to Murwillumbah Railway, American style trusses (with large diameter pins now being replaced by riveted joints) became standard for all major rail and road bridges through to the advent of welded girders and developments with pre-stressed concrete box girders in the 1960s.

The application of American steel trusses to major road bridges in New South Wales began with two bridges over the Hunter River at Luskintyre and Singleton (see Section 4.16).

1.4 Buckled Plate Floors

Iron was an expensive import during the colonial period (refer Section 3.5) to the extent that its use was restricted to the main structural components of bridges, that is, the piers of the substructures and the beams and trusses of the superstructures. The usual cost saving device was the use of timber for the approach spans and for the decks.

Typical timber beam bridge deck,
its log girders and plank deck.

Elevation of timber approach.

However, with low initial costs, timber decks had high long term costs due to their need for replacement approximately every 20 years.

Typical timber deck on a lattice bridge at Forbes and the use of buckled plates

Buckled plates were a form of decking support which provided a rigid connection between beams and cross girders and gave a permanent smooth riding surface. The term 'buckled' is something of a misnomer because it implies collapse whereas the plates were simply dish-shaped and attached, dome upwards, to the tops of the beams or cross girders to form a waffled iron floor. This was then covered with concrete or a similar material to form the road surface.

The distinction between rough, exposed timber decks and smooth surfaces provided by buckled plates.

The buckled plate floor has proved to be a cost-effective component of bridge decks and its use, or some variants, has been continued through to modern times even though types of temporary reusable formwork units between beams have been developed. For example, the 1929 Tom Ugly's Bridge has a buckled plate floor with a concrete running surface (refer Section 4.26).

Underside of concrete slab exposed after temporary formwork has been removed.

1.5 Iron and Steel

Iron is the most important of the industrial metals. Its basic alloys, cast iron, wrought iron and steel, are the world's cheapest and most useful metals. They are the key to the development of our modern civilisation, particularly since the start of the industrial revolution over 200 years ago. From bridges to railways, ships, motor vehicles, machinery, canned foods, knives and forks, even reinforced and pre-stressed concrete, iron and steel have played a fundamental role.

Iron is a generic term that can be applied to the pure element, iron, or to its alloys, particularly cast iron and wrought iron, but not generally to steel because it has proved to be "something different" and is by far the more important and dominant metal. Steel bridges are usually referred to as metal bridges, not iron bridges, such is the important distinction between the two.

The three basic iron alloys consist almost entirely of two elements, iron and carbon, with iron usually in excess of 95% and carbon at a maximum of 4%. Special alloys have other elements added, usually at the expense of the iron, in order to achieve particular characteristics. For example, non-corrodible stainless steel has 12–30% chromium and some nickel, whereas manganese imparts hardness and long wearing qualities.

When viewed through a microscope, iron appears as a collection of grains. Pure iron has a useful strength (equal in tension and compression), is easily worked into shapes by rolling or forging (it is malleable) and is weldable. When overstressed, it deforms by a large amount before breaking (it is ductile), but it is relatively soft and so is easily abraded. Wrought iron is almost pure iron but it is the result of an expensive manufacturing process.

The introduction of carbon changes all these basic characteristics, initially for the better then gradually for the worse. As little as 0.25% creates mild steel, which is a much stronger metal than wrought iron because the carbon lodges between the iron grains causing a locking action that resists deformations. However, malleability, ductility and weldability remain good. Being readily rolled into plates, bars, wire and a large range of structural shapes, it is the most widely used steel. Its manufacturing process, incorporating large open hearth furnaces, allows huge quantities to be made much more cheaply than wrought iron.

As the amount of carbon increases, it continues its locking action but begins to push the iron grains apart. The introduction of 0.45% carbon creates high strength steel with a doubling of strength but at the expense of a significant loss of malleability, ductility and weldability. Loss of ductility means an increase in brittleness, hence high strength steels are susceptible to fatigue failure in which variations of internal stress cause minute cracks to progressively increase until fracture.

By the time the percentage of carbon reaches 1%, strength is still high but the other characteristics are unsuitable for structural use, such as bridges. However, the steel is very hard and is therefore widely used for machine parts and tools.

At 2%, all these characteristics have disappeared and cast iron is the result. It has useful compression but negligible tensile strength. It cannot be rolled or worked but has improved fluidity suitable for casting into moulds, hence the name cast iron. Under load, particularly in tension, it fractures without signs of distress as it is now brittle (a dangerous condition) and so it cannot be welded. It has become a niche product suitable for particular applications such as columns in buildings and trestles for bridges.

At 4% carbon the metal is useful only where sheer mass is desirable, such as engine blocks for motor vehicles.

Historically, steel and high strength steels have been used for two thousand years but mainly in weaponry, particularly for swords. The high costs of labour intensive production and the small quantities produced meant that steel was not available for general use, such as for bridges. But cast iron was well known and widely used. It was cheaper to make and large quantities could be produced.

Ironbridge, the first metal bridge over the Severn River, England

The first metal bridge, the 1779 Ironbridge in England, was an open, lightweight arch, a basic compression structure, for which cast iron was ideal and affordable.

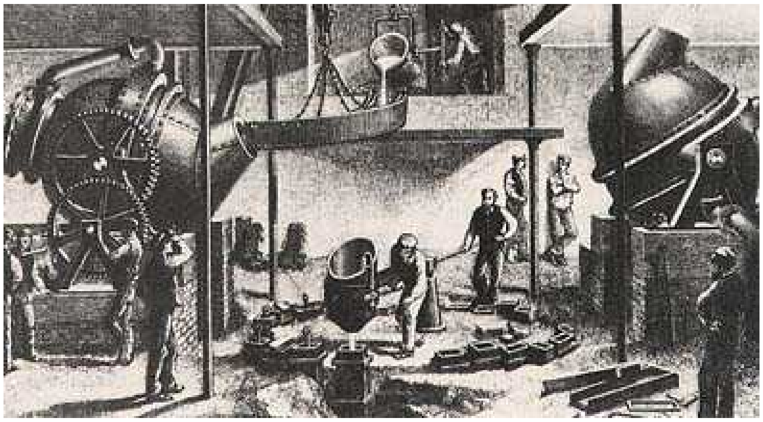
Concurrently, ironmakers were experimenting with methods to refine cast iron, as had been done by blacksmiths for centuries, but in economic quantities. The most successful method was developed by Henry Cort in England in 1783. His "puddling" process raised a quantity of cast iron to a spongy white-hot mass that was beaten under a forge hammer (it was wrought or worked or shaped) such that the impurities and the carbon were oxidised and squeezed out as a slag. The process was repeated a number of times until a uniform mass of near pure iron was obtained. It was malleable and was able to be worked into many forms, merchant bars or structural sections. This was wrought iron.

It was an outstanding contribution to iron technology and increased production from one ton per day to 15 tons per day. This process provided the means for making pure iron of reasonably uniform quality and in quantities needed for the great industrial expansion of the early 1800s. Wrought iron became the major civil engineering material for railways and bridges where the brittleness of cast iron made it unacceptably dangerous. However, when appropriately used, a mix of cast iron and wrought iron elements could create useful bridges in which compression members are cast iron and tension members are wrought iron. There are some 150 year old examples still in use in England and Europe.

The quest to further improve wrought iron continued. Experience had shown that small amounts of carbon could increase strength, but the manufacturing process beat it all out again. A new process was required.

The labour intensive effort of producing wrought iron.

The breakthrough came in 1856 when Henry Bessemer invented his converter, basically an iron pot with holes at the bottom by which air could be blown through a molten mass of cast iron to oxidise the impurities in only about 20 minutes. The resulting pure iron could then be transferred to another furnace where pre-determined amounts of carbon, or any other alloying material, could be added. An economical process for the production of steel had been invented. It lead to the mass production of uniformly reliable, low cost steel which was stronger than wrought iron, was equally strong in tension and compression, was malleable, ductile and tough – a wonder material.



Two Bessemer converters in use.

Two aspects of civil engineering benefited enormously from the availability of this new metal. Railway networks were built in countries all around the world and very large bridges were built across waterways that had been hitherto considered impassable, except for ferries and punts. The famous Firth of Forth railway Bridge is a classic example.

The famous 1890 Forth Bridge, Scotland.

In New South Wales, industrial development, including railways and bridges, took place in the second half of the nineteenth century. The only local iron industry was the Fitzroy Iron Works at Mittagong, started in the 1850s, which only refined cast iron into merchant bars. It did, however, supply the cast iron cylindrical rings for the piers of the 1867 Prince Alfred Bridge at Gundagai. Local cast iron was also used to a limited extent for structural purposes. There are some cast iron floor girders in some old buildings in Sydney's CBD and the King Street Bridge over the railway at Newtown has cast iron beams made in 1892 by Hudson Brothers (Clyde Engineering).

An 1892 cast iron beam at King Street, Newtown and the maker's name.

New South Wales was dependent on wrought iron from England, an expensive import. Despite this, some splendid iron bridges, road and rail, were built between 1873 and 1893, of special note being the lattice truss bridges with spans up to 160 feet (49 metres).

An 1884 sturdy British lattice bridge and the 1901 American Pratt trusses.

Economic quantities of structural steel did not begin to arrive until the 1890's which coincided with the change from British to American bridge technology. The most notable change in the bridges was visual, from the sturdy somewhat heavyweight British lattice bridges made from larger quantities of the weaker wrought iron, to the lightweight American trusses made from the stronger metal, steel.

This advantage was first demonstrated on a large scale with the 415 foot (126 metre) steel trusses of the first Hawkesbury River railway Bridge, completed in 1890.

The largest bridge in colonial New South Wales, the American designed Hawkesbury River railway Bridge.

By 1900, steel had displaced wrought iron, virtually world wide, and its dominance in civil and structural engineering has continued ever since. Larger buildings and larger bridges are clear evidence of its superiority.

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Concrete Beam Bridges

Heritage Study of Pre-1948 Concrete Beam Bridges (Sydney, South West and Southern Regions)

2005

HISTORY OF CONCRETE BEAM BRIDGES IN NSW

1.1. History of Reinforced Concrete

The first report prepared by BRW and HAAH detailed the development of concrete and then reinforced concrete for use in bridges[1]. To enable this current report to be used as a stand-alone document, those sections of the previous report are replicated below, incorporating some amendments as more information emerged through this current study.

1.2. Timeline of Reinforced Concrete

The following timeline summarises the history of the material now referred to as reinforced concrete up to 1918. Its path to the form used in bridges in New South Wales up till 1948 represents one of the successes of the industrial age by bringing together physics, chemistry, engineering and innovation to produce a product that has given excellent service to the community. The timeline, of course, did not stop at 1918, and this report also records what has happened to the various bridges since then, and their current role in the infrastructure of the state. However, the major technical advance in concrete, the introduction of prestressing, is outside the scope of the current study and is thus omitted.

REINFORCED CONCRETE TIMELINE TO 1918

12,000,000 BC	Reactions between limestone and oil shale during spontaneous combustion occurred in Israel to form a natural deposit of cement compounds. The deposits were characterized by Israeli geologists in the 1960's and 70's.
3000 BC	Egyptians used mud mixed with straw to bind dried bricks. They also used gypsum mortars and mortars of lime in the pyramids.
7th to 2nd C BC	Chinese used cementitious materials to hold bamboo together in their boats and in the Great Wall.
800 BC	Greeks, Cretans & Cypriots used lime mortars which were much harder than later Roman mortars.
300 BC	Babylonians & Assyrians used bitumen to bind stones and bricks.
300 BC - 476 AD	Romans used pozzolana cement from Pozzuoli, Italy near Mt. Vesuvius to build the Appian Way, Roman baths, the Colosseum and Pantheon in Rome, and the Pont du Gard aqueduct in south France. They used lime as a cementitious material. Pliny reported a mortar mixture of 1 part lime to 4 parts sand. Vitruvius reported a 2 parts pozzolana to 1 part lime. Animal fat, milk, and blood were used as admixtures (substances added to cement to improve the properties.) Many structures still exist. Bronze cramps were used to reinforce masonry in the Colosseum.
1200 - 1500 The Middle Ages	The quality of cementing materials deteriorated. The use of burning lime and pozzolan (admixture) was lost, but reintroduced in the 1300's. Gothic builders in Northern France used iron ties and cramps. Damage due to rust spalling led to abandonment of the method.
17th	Claude Perrault used armature of embedded iron for long span architraves in his colonnade in

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[1] Study of Heritage significance of Pre-1948 RTA Controlled Concrete Slab and Concrete Arch Bridges in NSW by Burns and Roe Worley Pty Ltd in association with Heritage Assessment and History, February 2004

Century	the Louvre.
1678	Joseph Moxon wrote about a hidden fire in heated lime that appears upon the addition of water.
1779	Bry Higgins was issued a patent for hydraulic cement (stucco) for exterior plastering use.
1780	Bry Higgins published "Experiments and Observations Made With the View of Improving the Art of Composing and Applying Calcareous Cements and of Preparing Quicklime."
1793	John Smeaton found that the calcination of limestone containing clay gave a lime which hardened under water (hydraulic lime). He used hydraulic lime to rebuild Eddystone Lighthouse in Cornwall, England which he had been commissioned to build in 1756, but had to first invent a material that would not be affected by water.
1796	James Parker of England patented a natural hydraulic cement by calcining nodules of impure limestone containing clay, called Parker's Cement or Roman Cement.
1802	In France, a similar Roman Cement process was used.
1812 -1813	Louis Vicat of France prepared artificial hydraulic lime by calcining synthetic mixtures of limestone and clay.
1812-1824	The world's first unreinforced concrete bridge was built at Souillac, France by Louis Vicat.
1824	Joseph Aspdin of England invented Portland cement by burning finely ground chalk with finely divided clay in a lime kiln until carbon dioxide was driven off. The sintered product was then ground and he called it Portland cement named after the high quality building stones quarried at Portland, England.
1828	I K Brunel is credited with the first engineering application of Portland cement, which was used to fill a breach in the Thames Tunnel.
1836	The first systematic tests of tensile and compressive strength took place in Germany.
1849	Pettenkofer & Fuches performed the first accurate chemical analysis of Portland cement.
1849	Joseph Monier of France commenced producing concrete tubs for orange trees using wire reinforcing.
1851	A beam consisting of brickwork reinforced with hoop iron was displayed at the Great Exhibition.
1854	Patent 2293 by W B Wilkinson of Newcastle, England for concrete floor with network of flat iron bars or wire rope sagging near centre of span. Not significantly commercialised.
1862	Blake Stonebreaker of England introduced jaw breakers to crush clinkers.
1865	Mass, unreinforced concrete used for multiple arch Grand Maitre Aquaduct to convey water to Paris
1867	Joseph Monier of France patented reinforced concrete portable containers.
1867-72	Patents issued to Monier for reinforced concrete pipes and bridges.
1875	First reinforced concrete bridge (of four beams with composite deck) built by Monier at Chateau de Chazelet, Indre, France
1884-1891	Wayss & Freitag acquired patent rights and built a claimed 320 reinforced concrete arch bridges with spans to 40m.

1887	Wayss published "Das System Monier", incorporating theory developed by K Koenen
1894	Experimental Monier arch on Parramatta Road, Burwood as culvert.
1896	Aqueducts over Johnstons and Whites Cks at Annandale by Carter Gummow & Co.
1896	Unreinforced arch bridge over Black Bobs Creek near Berrima by J W Park
1899	The first reinforced concrete bridge built in Victoria: Anderson St Bridge, by Carter Gummow & Co
1900	The first reinforced concrete Monier arch bridge built in New south Wales: Reads Gully near Tamworth, by Carter Gummow & Co
1905	Bridge over the Hawkesbury River at Richmond using Monier arches
1907	First reinforced concrete beam bridge in New South Wales, at Rockdale
1918	First continuous beam bridge, Fullers Bridge, Lane Cove

Prime references:[2],[3].

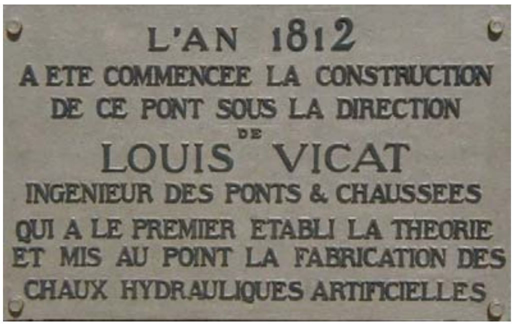
1.3. The Evolution of Concrete Technology – International Context.

The timeline above demonstrates the long path from the earliest uses of cementitious materials to the application of steel and concrete for the construction of bridges. Two keys were required to unlock the door: strong cements, and the means to carry tensile forces.

The Romans had used a cement sourced from the Italian town of Pozzuoli, mixed with lime, sand and water c.400BC – 476AD. This material was used as a binder in piers and arch spandrels, but also in mass footings.[4] In the following centuries the use of cement was largely lost although lime mortars (made by burning seashells for example) were common.

Louis Vicat in France, an engineer (Ingenieur des Ponts et Chaussees) initiated scientific studies of natural cements to reveal for the first time an understanding of the chemical properties of hydraulic (meaning it would set under water) cement. Between 1812 and 1824 he supervised the construction of a seven span unreinforced concrete bridge over the Dordogne River. Known as Pont de Souillac or Pont Louis Vicat, it has a total length of 180 m and utilised his artificial hydraulic lime.[5]

Pont de Souillac by Louis Vicat 1812-1824



Plaque on Pont de Souillac (source www.structurae.de)

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[2] "The History of Concrete" Materials Science and Technology Teachers Workshop, University of Illinois. Website //matse1.mse.uiuc.edu/~tw/concrete/hist.html

[3] International Database and Gallery of Structures www.structurae.de

[4] "Context of World Heritage Bridges" A Joint Publication with TICCIH, 1996 by Eric DeLony www.icomos.org/studies/bridges

[5] International Database and Gallery of Structures www.structurae.de

In 1824 an artificial Portland cement was developed in England by Joseph Aspdin using a mixture of clay and limestone, calcined and finely ground. The use of these materials began to extend through the building industry as their utility became better appreciated. In 1828 Isembard Kingdom Brunel was credited with the first application of hydraulic cement to repair a breach in the Thames Tunnel which his father had designed.[6]

By 1865 unreinforced concrete had been used in France to build a mass concrete arch aqueduct, continuing to use the compressive strength of the concrete in exactly the same manner as stone which has been used in arch bridges for at least two thousand years. In this instance, it was used for a multiple arch aqueduct (Grand Maître Aqueduct), conveying water from the River Vanne to Paris.[7]

However, this use still reflected the limitations of masonry, which was its inability to carry tensile loads. Even when using stones with good tensile strength, the joints between blocks would not pass any dependable tensile forces. This shortcoming of masonry had been addressed in a variety ways over the centuries but with insufficient success to permanently change the way materials were used. China's oldest surviving bridge, of open spandrel arch construction, is the Zhaozhou Bridge (c AD 605), attributed to Li Chun and located in Hebei Province south-west of Beijing. Its thin curved stone slabs were joined with iron dovetails so that the arch could yield without collapsing.[8] This articulation allowed the bridge to survive the movements of abutments bearing on spongy, plastic soils, and also the effects of moving traffic loads. In Europe, bronze cramps had been used by the Romans in stone masonry in such structures as the Colosseum in Rome.[9] From the 12th Century, gothic builders used iron ties and cramps in cathedral construction. Unfortunately, damage in the form of rust spalling led to the abandonment of the method. In the 17th Century, Claude Perrault depended on an armature of embedded iron to achieve the long span architrave of his colonnade in the Louvre, Paris. The French-born engineer and innovator Marc Isembard Brunel (1769-1849) experimented with reinforced brickwork in 1832; and a beam of hoop-iron reinforced brickwork was displayed at the Great Exhibition of 1851. However, none of these approaches addressed the problem of corrosion of iron which increases its volume by a factor of 6 (causing bursting or spalling of material around it), not to mention the loss of strength as the iron turns to iron oxide (rust).

Joseph Monier 1823-1906
(source www.structurae.de)

The solution to this problem came from an unexpected source. In 1867, a French gardener, Joseph Monier was granted a patent for cement flower pots strengthened by iron-wire mesh embedded in the concrete and moulded to curvilinear forms. He had begun making such pots in 1849.[10][11] During this period to 1867 several other patents were granted to other innovators including: in 1848 for a reinforced concrete boat; in 1855, for the use of iron in combination with cement as a substitute for wood; and in 1854, for a concrete floor with a network of flat iron bars or wire rope.

While Monier was thus not the first to put cement and steel together, he was the first to trigger its use in bridges. He lodged a patent extension on 13 August 1873 for the construction of bridges and footbridges

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[6] "The History of Concrete" Materials Science and Technology Teachers Workshop, University of Illinois. Website //matse1.mse.uiuc.edu/~tw/concrete/hist.html

[7] "The History of Concrete" Materials Science and Technology Teachers Workshop, University of Illinois. Website //matse1.mse.uiuc.edu/~tw/concrete/hist.html

[8] "Context of World Heritage Bridges" A Joint Publication with TICCIH, 1996 by Eric DeLony www.icomos.org/studies/bridges

[9] "A note on the history of reinforced concrete in buildings" by S.B. Hamilton HMSO London 1956

[10] "A note on the history of reinforced concrete in buildings" by S.B. Hamilton HMSO London 1956

[11] "Joseph Monier et la naissance du ciment armé" by J-L Bosc et al,Editions du Linteau, Paris 2001

made of iron reinforced cement.[12] In 1875 he built the world's first reinforced concrete bridge, a four beam footbridge of 13.8m span and 4.25m width at the Chateau de Chazelet, Indre, France.[13]

(By way of context, in the same year patents were taken out for the electric dental drill and blasting gelatin!) As he was not an engineer in a country which had a strong engineering heritage, (the Ecole Nationale Des Ponts et Chaussées was established in 1747) he was not permitted to design or build bridges for general public use. He therefore on-sold his patents in 1884 to German and Austrian contractors Wayss, Freitag and Schuster.

Bridge at Chateau de Chazelet, France (photos Sid French)

Underside of bridge showing four curved beams and retrofitted central prop to allow tractors to cross the bridge

Interestingly, the history of Wayss[14] suggests that they obtained the patent rights gratis, perhaps evidence of a lack of business acumen which ultimately led to Monier dying a pauper in 1906. Wayss, Freitag and Schuster built the first commercial reinforced concrete bridges in Europe: the Monierbrau footbridge of 40 m span in Bremen in Germany, and the Wildegg Bridge with a span of 37 m in Switzerland. It is reported that by 1891 they had built 320 arch bridges.[15] (A somewhat questionable claim for such new technology in only seven years)

As part of the process of developing reinforced concrete design, Wayss initiated strength testing of this new combined material, and had K Koenen develop a system of computation. This was published in 1887 as "Das System Monier", and incorporated the following principles:

- Steel alone took the tensile loads
- Transfer of force to the steel from the concrete took place through adhesion
- Volume changes in both materials due to temperature could be assumed to be approximately equal
- For calculations of bending, the neutral axis was assumed to be at the mid-depth of the section

In 1890, Prof Paul Neumann, Professor at the Technical School of Brunn published a memoir on calculation using Monier construction in which he corrected the location of the neutral axis. This basically put the design of reinforced concrete into the hands of general civil engineers. This remained the theoretical basis for design until the middle of the 20th Century, when design based on ultimate strength criteria began to displace elastic design principles.

Whilst the bridges of Wayss et al were the first of the genre, the period saw a proliferation of patents and applications for reinforced concrete. These took advantage of improvements in available cements and

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[12] Additif au brevet No 77 165 : "Application a la construction des ponts et passerelles de toutes dimensions"

[13] International Database and Gallery of Structures www.structurae.de

[14] International Database and Gallery of Structures www.structurae.de

[15] "A note on the history of reinforced concrete in buildings" by S.B. Hamilton HMSO London 1956

delivered structures considered to have enhanced features including fire and corrosion resistance, and freedom of form. Reinforced concrete began to be widely used in construction of civil works, domestic and then commercial buildings.

Pont Camille de Hogues (Pont de Châtellerault) 1899-1900 First notable reinforced concrete bridge.

PONT
CAMILLE DE
HOGUES
1899

Destiné à desservir la manufacture,
cet ouvrage de 155 m de long, porte le
nom de son commanditaire, le maire
de Châtellerault de 1896 à 1904.
C'est le premier pont construit en
béton armé en France. Les travaux
conduits par l'architecte Duprez n'ont
duré que 4 mois. Aujourd'hui classé, ce
pont fut conçu par l'ingénieur français
Hennebique.

Plaque on bridge
(photos Sid French)

The first firm to market reinforced concrete bridges internationally was formed by Frenchman Francois Hennebique who also held various patents for improvements to the art. His bridge at Châtellérault in 1900, listed as having potential to be considered as a World Heritage Bridge, remains one of the first notable reinforced concrete arch bridges in the world, with a central span of 52m and two side spans of 40m.[16]

Outside Europe the reinforced concrete bridge began to spread, but sporadically. The first known reinforced concrete bridge in the USA was an arch built in Golden Gate Park, California in 1889.[17] New Zealand built several small footbridges in the Otepuni Gardens in Invercargill in about 1899 before their first road bridge in George Street Dunedin was constructed in 1903.[18] The bridge claimed to be the oldest in the UK is Chewton Glen near Milton in Hampshire, built in 1900.[19]

Otepuni Gardens footbridge c1899 (source Bridging the Gap by G Thornton)

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[16] "Context of World Heritage Bridges" A Joint Publication with TICCIH, 1996 by Eric DeLony www.icomos.org/studies/bridges

[17] "A Survey of Non-arched Historic Concrete Bridges in Virginia Constructed Prior to 1950" by A.B. Miller et al Virginia Transportation Research Council July 1996

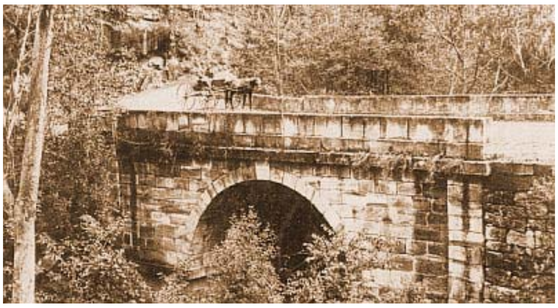
[18] "Bridging the Gap Early Bridges in New Zealand 1830-1939" by G. Thornton, published by Reed

[19] www.hants.gov.uk/environment/bridges Bridges in Hampshire of Historic Interest

1.4. The History of Reinforced Concrete Bridges in the Context of New South Wales

1.4.1. Introduction

Bridging streams was one of the first public works carried out in the fledgling penal colony of Sydney. The Tank Stream was spanned by a bridge made from local timber, in the first year of European settlement. At the time, it was noted that *"a gang of convicts were employed in rolling timber together to form a bridge over the stream at the head of the cove"*.[20] This set a pattern which was to continue into the twentieth century – of using the strong, plentiful, straight local hardwoods for bridge construction over streams. Larger rivers were forded or crossed by punts or ferries.



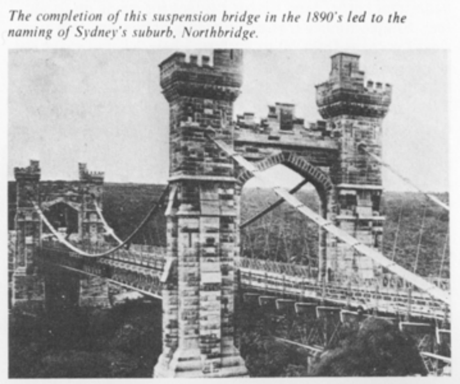
Lennox Bridge 1880s
(Source Mitchell Library scanned from Pictorial Memories Blue Mountains)

Although during the 1810s Governor Macquarie set his sights higher, and triggered a period of excellence in public works, no bridges of his period remain, largely because of a dearth of artizans skilled in bridge construction. The oldest surviving bridges are of stone arch construction over Lapstone Creek in 1833 and over Prospect Creek at Lansdowne in 1836, both by David Lennox. However, the vast majority of bridges built over the following eighty years were of timber. These were initially simple structures using timber for piers and abutments, with round logs forming the stringers of the deck, and topped with timber planking, all connected using iron bolts and spikes.

1.4.2. The Colonial Period

During the nineteenth century the need to span larger crossings, and to avoid piers in the water which degrade quickly and form an obstruction to flood debris, led to the development and adoption by the 1850s of a range of truss designs. These were typically named after the designers who developed their geometry, immortalising Allan, Warren, McDonald, Pratt and Howe amongst others. While Percy Allan was an Australian (Chief Engineer for National and Local Government Works, Public Works Department), they were not all local engineers (Pratt was an American for example). Information on the latest bridge design tended to spread fairly rapidly through the worldwide engineering community. Adoption of new ideas was, however (and remains) a slower process, being driven by a diverse set of constraint including cost, material availability, site suitability and various pragmatic issues such as individual preferences, resistance to change, and the cost of preparing new designs.

As the century wore on, iron in its various forms became more available and its use in bridges increased. Its ability to carry tensile loads led to truss forms wherein timber in the truss tension diagonals was replaced by wrought iron and then steel rods. Although complete iron bridges had been built elsewhere from the late
s not till 1851 that an all metal superstructure was erected in New
Subsequent bridges included the Prince Alfred Bridge over the
aving three continuous wrought iron spans, the Denison Bridge
0 using iron from the Fitzroy Iron Works at Mittagong, and Iron
y in 1882 and c1883 respectively. Complexity of metal structures
: opening spans becoming common, and with wrought iron
rial was also applied successfully to suspension
bridges (Hampden Bridge, Kangaroo Valley 1898 and Northbridge 1892).[21] Concrete saw its first role in bridges in New South Wales through the "back door". It was found to be a suitable material for filling the insides of cast iron pier caissons and the like, providing a filling which was not only



Northbridge (source The Roadmakers)

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[20] The Roadmakers A History of Main Roads in New South Wales, Department of Main Roads New South Wales, 1976

[21] The Roadmakers A History of Main Roads in New South Wales, Department of Main Roads New South Wales, 1976

strong and stable but also protected the iron from corrosion due to its alkalinity. It also began to make cameo appearances in the form of mass concrete for abutments. This actually revived a role concrete had filled for the Romans two thousand years earlier.

With the dominance of German speakers in the commercialisation of reinforced concrete bridges in the late nineteenth century it is not surprising that this link brought the technology to Australia. W J Baltzer, a German immigrant working for the New South Wales Public Works Department maintained contact with his brother in Germany, and through that link, awareness of the emerging technology. In 1890 he travelled to Germany to gather information on this new form of bridgebuilding. However, on his return he was unsuccessful in interesting his superiors in the technique and ultimately joined several businessmen to obtain licences through Wayss to cover the Australian Colonies.[22]

Their company, Carter Gummow & Co, built several small trial structures, apparently one of these being a culvert under Parramatta Road at Burwood in 1894.[23] Unfortunately, it is unclear if this structure is still extant. The current main crossing has a flat soffit and the semi-arched connection to an upstream circular pipe is of rough construction unlikely of a trial structure built to impress potential users.

Entrance to culvert under Parramatta Road Burwood

Arched connection from slab culvert to circular pipe under footpath

Carter Gummow & Co subsequently obtained contracts to build two large arched sewage aqueducts over Johnstons Creek and Whites Creek in Annandale.[24] Completed in 1896 they remain as probably the earliest reinforced concrete bridge-like structures in Australia.

Johnstons Creek Aqueduct, Annandale

Whites Creek Aqueduct, Annandale

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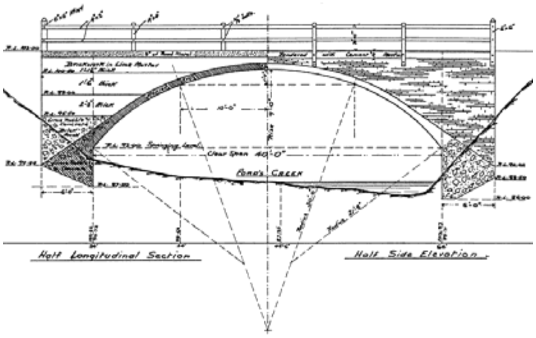
[22] **John Monash Engineering Enterprise Prior to** World **War I Introduction of Monier concrete to Victoria,** Australia http://home.vicnet.net.au/~aholgate/welcome.html

[23] Some Notes on the History of Concrete Bridges in N.S.W. by L.H. Evans Unpublished manuscript, stamped March 1986, held by RTA library, Parramatta

[24] John Monash Engineering Enterprise Prior to World War I Introduction of Monier concrete to Victoria, Australia http://home.vicnet.net.au/~aholgate/welcome.html

Baltzer became the Chief Engineer of Carter Gummow and in this role began promoting the technology. He spoke in 1897 to the Engineering Association of NSW, and the company held a stand at the Engineering and Electrical Exhibition in Sydney, gaining coverage in the Building Mining and Engineering Journal.



Monier arch, Fords Creek, Victoria(http://home.vicnet.net.au/~aholgate)

Monier arch construction, Victoria. (Source:State Library of Victoria)

In the same year Gummow and W C Kernot, Professor of Engineering at the University of Melbourne jointly mounted an exhibition on the subject in Melbourne. The partnership of John Monash and Joshua Anderson, which had formed in 1894, obtained from Gummow sole rights to the Monier patent in Victoria. In 1899 Anderson St Bridge was built by Carter Gummow & Co and then the Monash/Anderson partnership constructed two Monier arch bridges, at Fyansford and Wheelers Creek in 1900. Several others followed. In 1901 one of their bridges, Kings Bridge at Bendigo, collapsed whilst being load tested,[25] ultimately bringing the partnership down with it, but not before they had built a total of 15 bridges in the period 1899-1903. The Bendigo bridge was a heavily skewed arch. It collapsed under an unusually severe test load of a steamroller back to back with a steam traction engine, killing one man. The partnership was exonerated by the coroner when Professor Kernot of the University of Melbourne showed that accepted theory (as set forth in W J M Rankine's texts) greatly underestimated the stresses in skewed arches - by a factor of as much as four. Monash went on to establish the Reinforced Concrete and Monier Pipe Company, and progressively moved into beam type bridges rather than the arch concept which had proved so troublesome.

Kings Bridge collapse during load test by steam and traction engines – both visible (source http://home.vicnet.net.au/~aholgate/jm/)

Returning to New South Wales, the oldest existing concrete road bridge was constructed for the Public Works Department by J W Park of Gladesville in 1896 over Black Bobs Creek on the Hume Highway near Berrima.[26] Like the Pont de Souillac, it was unreinforced, having a 9.14m span and a width of 8.84m. It remained in service until the Highway was rerouted in 1971, despite the concrete having been made from low strength sandstone aggregate. It has been said in the RTA that the bridge was, in fact, detailed with the appearance of exposed stone to avoid problems from those who were nervous about the new technology of concrete.

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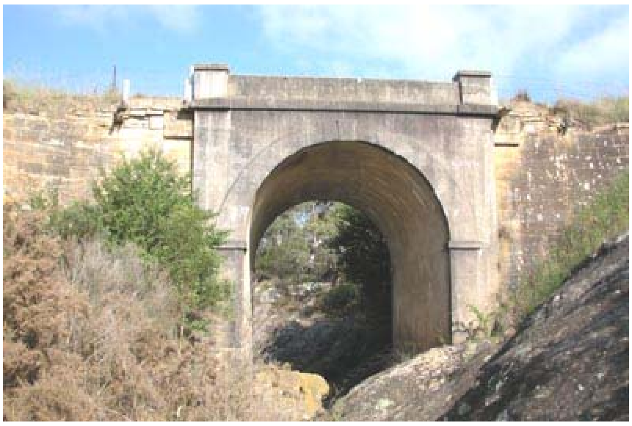
[25] John Monash Engineering Enterprise Prior to World War I Introduction of Monier concrete to Victoria, Australia History of King's Bridge Bendigo http://home.vicnet.net.au/~aholgate/jm/texts/kingshist.html

[26] Some Notes on the History of Concrete Bridges in N.S.W. by L.H. Evans Unpublished manuscript, stamped March 1986, held by RTA library, Parramatta

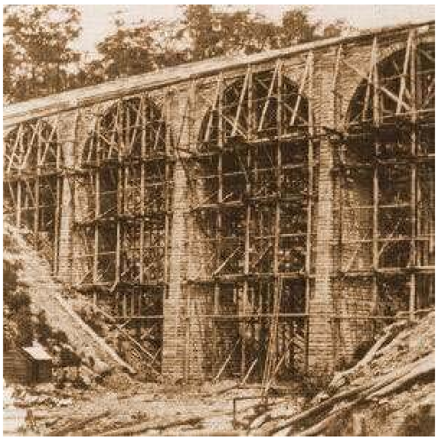


Black Bobs Creek Bridge, old Hume Highway alignment. Unreinforced concrete arch

Although this bridge is no longer in service and has passed to the care of the local council, there are current plans to improve its accessibility from an adjacent rest area, and install appropriate interpretive signage.

Whilst on the issue of unreinforced arches (i.e. the form leading to reinforced concrete arches) it should also be mentioned that brick and stone arches were also a very significant bridge form, not so much for road bridges as for rail. The spread of an extensive rail network throughout New South Wales saw a large number of brick and stone arches built, ranging in size from modest culverts to large multispan structures such as those visible west of Lithgow. One of these which has come into the RTA's portfolio is the sandstone multi-span arch over Knapsack Gully at Glenbrook. Originally built in 1865 as part of the centre leg of a zig-zag rail link up the eastern escarpment of the Blue Mountains, it consists of 7 arches, reaching a height of 38m at the centre. It was designed by John Whitton, engineer-in-chief of the Railways, and referred to as his masterpiece.[27] Abandoned in 1913 when the rail line was rerouted to avoid the delays of the zig-zag, it was widened and reopened in 1926 to carry the Great Western Highway. Another arch structure still in the RTA inventory was a brick arch built in 1840 over Duck Creek at Granville, servicing the Great Western Highway. A number of other masonry arches from the late nineteenth century are also still in service, including the Battle Bridge (RTA Bridge No 40) sandstone arch over the Hawthorne Canal at Petersham.

Lapstone masonry arch bridge (RTA Bridge No 967) (Photo NPB Photographics)



Lapstone Bridge during construction (source http://info.mountains.net.au/rail/lower/lapstone.htm

In 1900, six years after the trial culvert at Burwood, a Monier reinforced concrete arch was erected over Reads Gully on the Main Northern Road near Tamworth (presumably by Carter Gummow & Co who held the patent rights) at a cost of £406.8.6. The bridge served until it was replaced during a realignment of the New England Highway in 1937. It is now in the care of Parry Council.

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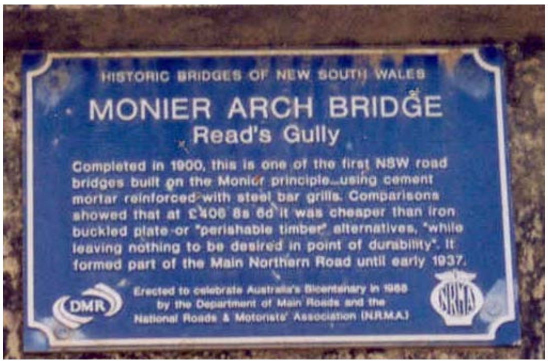
[27] The Roadmakers A History of Main Roads in New South Wales, Department of Main Roads New South Wales, 1976

Reads Gully Bridge, Tamworth 1900



HISTORIC BRIDGES OF NEW SOUTH WALES

MONIER ARCH BRIDGE

Read's Gully

Completed in 1900, this is one of the first NSW road bridges built on the Monier principle...using cement mortar reinforced with steel bar grills. Comparisons showed that at £406 8s 6d it was cheaper than iron buckled plate or "perishable timber" alternatives, "while leaving nothing to be desired in point of durability". It formed part of the Main Northern Road until early 1937.

Erected to celebrate Australia's Bicentenary in 1988
by the Department of Main Roads and the
National Roads & Motorists' Association (N.R.M.A.)

Plaque on Reads Gully Bridge, Tamworth

The Assistant Engineer for Bridges, Mr E M De Burgh mentioned in the Public Works Department Annual Report for 1900 that the Monier arch system would have been used more often if there had been more suitable sites.[28] Such a site was soon found at Richmond where the existing timber bridge was prone to damage during the frequent floods which submerged it, often with heavy loads of floating debris. Professor W. H. Warren of Sydney University acted as a consultant to the Public Works Department on the design which consisted of thirteen Monier style arches, two of 15.84m span and eleven of 16.45m. With a total length of 214.6m this 1905 structure was the longest reinforced concrete bridge in New South Wales for the next 25 years.

Bridge over Hawkesbury River at Richmond 1905 (RTA Bridge No 429)

1.4.3. Developments in the Twentieth Century

In support of the move to use reinforced concrete for local structures, Professor W.H. Warren, Challis Professor of Engineering at Sydney University and President of the Royal Society of NSW undertook research into the strength and elasticity of reinforced concrete utilizing local materials. Results of these investigations were published in the Journal of the Royal Society of NSW in 1902, 1904 and 1905.[29] Despite this supportive work, the number and scale of concrete bridges built in New South Wales over the next decade was small.

The first concrete beam bridge built in New South Wales was a small bridge over Muddy Creek on the Princes Highway at Rockdale in 1907 (deck now replaced and widened). The oldest extant slab bridge is over Muttama Creek at Cootamundra (RTA Bridge No 6438), built in 1914 whilst the beam bridge over American Creek near Figtree, built in the same year has now been replaced, as has a similar bridge over Mullet Creek,

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[28] Some Notes on the History of Concrete Bridges in N.S.W. by L.H. Evans Unpublished manuscript, stamped March 1986, held by RTA library, Parramatta

[29] W.H. Warren, " Investigations in regard to the comparative strength and elasticity of Portland Cement Mortar and Concrete when reinforced with Steel Rods and when not reinforced'. *Journal of the Royal Society of NSW*, Vol. XXXVI, 1902, pp.290-313; "Further Experiments on the Strength and Elasticity of Reinforced Concrete', *Journal of the Royal Society of NSW*, Vol. XXXViiI, 1904, pp.140-189; "Reinforced Concrete, Paper III', *Journal of the Royal Society of NSW*, Vol. XXXIX, 1905, pp.49-64.

Dapto of 1916 and concrete beam bridges at Throsby Creek Wickham and Shark Creek, Maclean. Extant from the same year is the slab bridge over Surveyors Creek at Walcha (RTA Bridge No. 3485).

Muttama Creek Cootamundra 1914 (RTA Bridge No 6438)

Surveyors Creek Walcha 1916 (RTA Bridge No 3485)

These structures, with deck geometries having either flat soffits or beams cast monolithically with the deck, represented a logical step forward in the use of reinforced concrete from the first spate of arch bridges, and actually reverted to the style used by Monier in his first bridge. The concrete arch did not in fact, efficiently utilise the freedom of geometry that reinforced concrete was able to offer. In the traditional masonry arch, avoidance of collapse was achieved by keeping the line of compression within the curved masonry. With a reinforced arch the same thinking initially applied, but with the advantage that the reinforcement could accommodate some local bending effects (such as from concentrated loads from heavy wheels) by using the tensile capability of the reinforcing in the concrete. However, these structures were still faced with placing filling on top of the arch to build an almost level surface for traffic, and this meant an overall heavy (and thus somewhat inefficient) structure. Once designers of reinforced concrete began to use the material in a manner which took advantage of its tensile capabilities, lifting the underside of the superstructure close to the top of the deck, design efficiency began to improve. Up to a span of several metres, flat slabs were efficient. Beyond that, by having a thin deck to carry the local wheel loads across to beams with steel reinforcement concentrated near the bottom, deck structures of up to 15 m were ultimately achieved.

The next step was to make the composite beam systems continuous over their supports. By making the deck continuous at the piers, adjacent spans effectively assisted each other by spreading a load on any one span along the bridge. In a typical span, by changing from simply supported to continuous, the bending moment due to self weight at midspan drops from M to M/3, whilst the moments at the supports go up from zero to -2M/3. There is thus a 33% net reduction in the bending moment to be designed for, and the peak occurs at the piers where extra beam depth can be provided efficiently. Placing the reinforcing steel predominantly in the bottom of the slab at midspan, and bending it up into the top over supports (where the bending effect is reversed) designers were able to place the steel effectively where the tension forces occurred. The bridge described as "the first true continuous girder reinforced concrete bridge" was Fullers Bridge across Lane Cove River, completed in 1918.(RTA Bridge No. 105)[30]. This has spans of 9.14 m. It is interesting that this continuous bridge has outlived all the simply supported span beam bridges erected before it.

Fullers Bridge (Bridge No 105) Note curved beam soffit, continuous over piers, providing deeper beams where the bending moments are greatest

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[30] Some Notes on the History of Concrete Bridges in N.S.W. by L.H. Evans Unpublished manuscript, stamped March 1986, held by RTA library, Parramatta

The conceptual logic contained in these early bridges was to persist with relatively modest changes until the introduction of prestressing in the 1950s. (As beam bridges are the core topic of this study, their design, numbers etc are more fully explored in Section 3.)

By the end of World War I there was the prospect of a substantial increase in both bridge building in general and in reinforced concrete in particular. In 1914 the Director General of Public Works stated that *"the increasing cost and difficulty in obtaining timber of suitable quality and dimensions for the large highway bridges determined me to adopt steel and ferro-concrete construction wherever practicable".* [31] In contrast with timber, the raw materials for reinforced concrete bridges: coarse aggregate, sand, cement and steel bars were becoming readily available.

The other driver was the explosion of private car ownership and the dramatic growth in truck transport of goods, with the weight of trucks growing continuously.

Croobyar Creek Bridge (Bridge No 730) Note curved deck with crossfall to suit high speed curve

The style of roads and bridges which had sufficed during the nineteenth century, wherein the road alignment and surface was subservient to the surroundings, was no longer acceptable for the higher vehicle speeds now emerging. Road design became a science in which the design speed dictated the minimum radius of vertical curves as well as horizontal ones. These were predicated on principles of safe stopping sight distances, and on limiting the lateral forces on vehicles. Previous rules, such as that mandated by the railways, that all overbridges must be at right angles to the rail line (to minimise soot effects from steam trains) began to be overturned, as were rules of thumb such as minimising the cost of bridges by making them straight and of minimum length (for example over rivers). Other parameters to evolve progressively during the Twentieth Century included the design weight of vehicles, the width of lanes, the provision of width to provide continuity with the shoulders of the roadway, and rules for impact resistance of railings. All of these have had their impact, not only on the design of new bridges but also on the continued appropriateness of existing structures and the need to modify them to maintain their level of service.

1.5. The Role of Government in Road and Bridge Expansion in NSW.

1.5.1. The Colonial Era

Prior to the granting of responsible government in the 1850s all authority and responsibility was exercised by the Crown's representative in the Colony of New South Wales, the Governor. Roads and bridges were constructed by decree of the Governor on the advice of his staff. These were the officers of the Colonial Architect's Branch of the Surveyor-General's Office. This system evolved at Federation into a structure containing three tiers of control: Federal, State and Local. Interfacing with this hierarchy was free enterprise, the entrepreneurial companies of which variously built roads and bridges for contracted amounts or were licensed to carry out works and collect tolls. The course of change through this process has been well documented in such works as *The Roadmakers*, and *Vital Connections.* During the period of interest for this current study, viz 1905 to 1948, many changes occurred. Leading to the period in question (and covering some of the earliest reinforced concrete works), the Department of Public Works (created in 1859) was put under the control of R Hickson as Commissioner in 1889 who separated the State into six divisions, each with its own Resident Engineer who reported to Divisional Engineers operating from Sydney

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[31] Some Notes on the History of Concrete Bridges in N.S.W. by L.H. Evans Unpublished manuscript, stamped March 1986, held by RTA library, Parramatta

David Lennox

In 1895 the Roads, Bridges, Harbours and River Branches were placed under the control of one officer with the title of Engineer-in-Chief for Public Works, and Hickson was appointed to this position. In the following year he was also made Under Secretary for Public Works.

1.5.2. The Twentieth Century

With the turn of the century, significant political change occurred. The States combined (with the blessing of the Crown) to form a new country, the Commonwealth of Australia, in 1901. The increase in population also led to further pressure for decentralisation of power, and the 1906 Local Government Act transferred to shires and municipalities the responsibility for care and maintenance of local roads and other public works. This was funded partly by council rates which were based on the unimproved capital value of land, and topped up by grants from the State and Federal governments under a variety of funding arrangements. As a result of the handover, the greater part of the state's 48,500 miles of roads and bridges were passed over to the care of local government, and in 1907 the position of Commissioner for Roads was discontinued. Unfortunately, this change led to a decline in the amount of money actually spent on roads in general, and main roads in particular, although a proportion of roads and bridges were declared National Works and were maintained by the Department of Public Works.

By the end of the First World War, the NSW roads were in a poor state with even national roads badly underfunded. In 1924, after years of haggling and politicking, the Main Roads Bill was introduced into the New South Wales Parliament and subsequently the Main Roads Board of New South Wales was created in 1925 with the powers to function as a State road authority, and with 12,840 miles of roads to care for. Within a year the Board was swamped with requests from councils eager to offload their road responsibilities, the cost of which had been escalating. Early planning reviews not only allocated funding to established roads, but also set in train plans for a dozen new roads linking areas of the state not well connected by the road system which, until then, had grown like the proverbial Topsy. These new roads required new bridges, a number of which form part of the present study.

It was not until 1927, after almost three years of wrangling between the Main Roads Board and the Department of Public Works that a clear definition of the lines of responsibility was achieved. The Department of Public Works took charge of roads and bridges in the Western Division, and the Main Roads Board took responsibility for Main and Developmental Roads in the Eastern and Central divisions of the State. Matters relating to other roads, including interfaces with the councils, were placed with the Department of Public Works.

To rationalise the system of road classifications, all roads were reviewed in 1928 and new classifications of State Highways, Trunk Roads and Ordinary Main Roads were introduced. These changes had substantial implications for funding of the various roads, and thus of the councils who carried out much of the work. In the same year the Main Roads Board decentralised its road design and construction activities to regional headquarters in Glen Innes, Tamworth, Parkes, Queanbeyan, Wagga Wagga and Sydney. While it was feasible to set up road design teams in these offices, the high level of professional skill required for bridge design (and the more peaky nature of the workload) was seen as justification for keeping the bridge design team together in Sydney, at the Board's offices in Castlereagh Street.

More political machinations and funding skirmishes saw the Main Roads Board dismantled in 1932 and replaced by the Highway and Roads Transportation Branch of the Department of Transport. In the aftermath of a dogfight between the State and Federal governments (during which the funds of the State were garnisheed by the Commonwealth), the Department of Main Roads was created in 1933, a bureaucratic arrangement which lasted until 1989. These organisational changes occurred during (and perhaps because of) confronting times of economic depression and high unemployment.

From 1932, motor vehicle registrations grew at the astonishing annual rate of 48% in a period of 4% population growth and with a depressed economy. As the motor vehicle moved from being an unreliable and relatively slow contrivance to an essential high speed means of transport, new concepts for roads began to emerge, including multilane roads, grade separated intersections, speed limits, removal of level crossings, and, in the country, separation of roads from stock routes. Thus the focus changed from making the roads passable to making them safe and efficient. By 1938 the total length of roads covered by the Department was 24,643 miles. This was a boom period for the construction of simple, functional concrete bridges which embodied the new standards, to replace decrepit timber structures or flood prone open crossings on roads controlled by the Department. (Whilst not part of this study, the same pressures were also being felt at the local government level with respect to bridges on local roads. However, with lower levels of funding their inventory of bridges typically lagged behind).

The prospect, duration and aftermath of World War II meant that defence priorities overshadowed civic factors in the development of roads and bridges over the final 10 years of the period under study. The decisions regarding which roads would be built and which bridges built or upgraded were made on defence criteria ahead of general traffic management issues. Key issues included the ability to move troops and military hardware rapidly from military facilities to strategic defensive locations. North-south lines of communication were seen as particularly important, with potential invasion expected from the north. Further downsides of the war included the diversion of funds and personnel away from non-strategic infrastructure. Contractors with bridges already committed to construction found difficulty getting tradesmen and materials to complete their works, and the Department was asked for extensions of contract times in many cases.

Coming out of the War, there was another hiatus as the community and bureaucracies refocussed. This meant another difficult period of limited access to equipment, materials and personnel even for urgent works, some of which had been held over from prior to commencement of hostilities. The War had seen a further jump in motor vehicle technologies and with it a new era of road planning began to implement more of the ideas regarding traffic management conceived in the 1930s, but not brought to fruition. The late 1940s thus closed out an era, to be replaced by a new world of freeways and prestressed concrete.

1.5.3. Key Bridge Design Personnel

The following table identifies many of the key engineers involved with the design or design management of bridges in NSW, with particular reference to the period under study. The list is provided to help readers understand the flow of engineers and managers who drove the design processes of the road bridge network. Where information has been available to link individuals to bridges, this has been identified. Unfortunately, in the majority of the bridges under study, little remains in the RTA files to identify the actual designers. Where original drawings (or copies thereof) are on file, the initials of designers are sometimes discernable and these have been acknowledged in the inventory. However, the practice of not including the designer's full name on the drawings, and giving him recognition on the bridge itself, all conspire to hide the identity of the individuals who created the original designs.

Having said that, it should be recognised that bridge design, like many other areas of human endeavour, is generally not the work of one person alone, but the progressive total of those who have gone before in developing earlier designs, of field personnel who gather data necessary for proper assessment of foundations, waterways etc, of peers carrying out design checking and drafting, and of management who ensure that all aspects are orchestrated efficiently and within overall budget constraints.

In the instance of slab and beam bridges in particular, the modest scale of most crossings has meant that designs became more or less standardised, with individual bridges being created by use of standard spans, piers and abutments. These standard designs tended to stay in use for some years until the march of progress, in the form of increased traffic design loads or improved material properties (such as concrete strength) meant that revision was warranted, leading to an updated standard design.

TABLE 2.5.3.1 KEY NAMES IN BRIDGE DESIGN, NSW[32]

Title	Name	Start Date	End Date	Significant Work
First *Superintendent of Bridges*	David Lennox	June 1833	1843	Lennox Bridge Lansdowne Bridge
Commissioner and Engineer-in Chief for Roads	W.C. Bennett	1862	1889	
Engineer-in-Chief for Public Works	R. Hickson	1889	1901	
Professor of Engineering, Sydney University	Prof W.H. Warren	1883	1925	Northbridge suspension bridge, Richmond Bridge
Bridge Modeller & Bridge Computer	H.H. Dare			Richmond Bridge
PWD Engineer	John A. MacDonald			MacDonald truss bridges
Chief Engineer for National and Local Government Works	Percy Allan	?	46 years	Allan truss bridges; Associated with more than 550 bridges
Chief Engineer, Sydney Harbour Bridge and Metropolitan Railway Construction, PWD	Dr J.J.C. Bradfield 1867-1943	1891 (Started with PWD) 1912	1932	Sydney Harbour Bridge
Supervising Bridge Engineer	E.M. De Burgh	1891 (?)	1900?	De Burghs Bridge, Lane Cove
Bridge Engineer (Transferred from Public Works)	Spencer Dennis	1928	1951	Promoted use of Reinforced concrete
Bridge and Designing Engineer	H.M. Sherrard	1926	1928	
Assistant Bridge Engineer	F.W. Laws	1935	1942	
Assistant Bridge Engineer	C.A.M. Hawkins	1944	1946	
Assistant Bridge Engineer	R.A.J. Thompson	Jan 1946	Nov 1946	
Assistant Bridge Engineer	A.J.Clinch	1946	1953	
Bridge design engineer	Vladimir Karmalsky	1930s	1950s	Bow-string arches

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[32] The Roadmakers A History of Main Roads in New South Wales, Department of Main Roads New South Wales, 1976

Title	Name	Start Date	End Date	Significant Work
Bridge design engineer	A.T. (Sandy) Britton	1930s	1950s	Shark Ck, Hillas Creek (bow-string arches)
Bridge design engineer	A Halvorseth	1930s	1950s	Tuena River (through girder) Galston Gorge Bridge and others

1.6. The Reinforced Concrete Bridge as an Element of Public Infrastructure

1.6.1. Introduction

Despite the arduous process required of Baltzer and others to get reinforced concrete bridges accepted as a valid medium, the social, economic and environmental impact of these bridges during the twentieth century has been immense. From a standing start at the turn of the century, they achieved the status of preferred bridge form for small to medium spans, and were seen as providing the flexibility that would allow the greatest spans to be contemplated. They are now a ubiquitous part of the landscape, generally providing many years of troublefree service to the community and representing a substantial part of the bridge infrastructure of the state. Bridges built to variations on the beam design are found in a great range of natural and cultural landscapes, and facilitate social and economic life in a great range of communities across NSW.

1.6.2. Bridges as Infrastructure

The bridges comprising the study group are all under RTA-control by virtue of being located on main roads, and in the context of this study, in the Sydney, Southern and South West Regions. Several of the great highways of NSW are represented. Almost one third of the seventy-eight bridges in the study group are located on the Princes Highway, spread out between Wollongong and the Victorian border. Three of the bridges are located on the Great Western Highway, and two on the Hume Highway. Approximately one third of the bridges in the study set are located in the Sydney area, on main roads such as Pittwater Road in the north or Woodville Road in the west. In the south western part of the State the Sturt Highway and Olympic Highway are among the transport conduits of which bridges in the study set form a part. Many of these routes have long and rich histories which are intimately related to the patterns of economic, social and environmental history in the regions or suburbs they traverse. The roads on which the bridges are situated are the context for the bridges' planning, construction and use, and provide much of the historical context and landscape context in which they are located.

Several of the bridges in the study group cross major waterways – the Hawkesbury River, Lane Cove River, and the upper reaches of the Wonboyn, Woronora and Wollondilly Rivers. Here the bridges have played a major part in the development of important routes, replacing punts or less reliable lower level bridges. In doing so they have also become dominant features in the landscape and are perceived as important infrastructure items by the community. For example, Fullers Bridge across the Lane Cove River when constructed in 1918 formed the first bridge link across the river linking the Willoughby and Lane Cove municipalities via Fullers and Delhi Roads. The bridge is an impressive structure which has retained a dominant place in the landscape and has excited continued interest in the community from the early stages of its planning in 1898, when a meeting of the Lane Cove and Willoughby Councils[33] discussed the siting of the bridge, to the present.

While most of the bridges in the study group are more modest structures crossing more minor waterways, their value as infrastructure on the State's major transport conduits should not be underestimated. The

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[33] Willoughby Mayor's Minute Book; record of meeting of Willoughby and Lane Cove Councils, 5 September 1898

crossings are characterised typically by various combinations of steep gullies, bogging sands, rapidly rising freshes or persistent flooding, and have the potential to form considerable obstacles to traffic.

The bridges in the study group were predominantly built in the period 1925-1948, by which time the vast majority of the routes which form today's main roads were well established transport conduits, often on generally the same alignment presently followed. These roads had developed as tracks and stock routes through the early to mid twentieth century, many likely to have followed Aboriginal pathways, and been formalised and improved through the mid to late nineteenth century under colonial administration, the Department of Public Works and local government administration from 1906. The majority of bridges in the study group therefore replaced a previous bridge, generally timber, on the same site, or were built on short deviations which improved the alignment of an existing route across the waterway in question. In several cases, the concrete bridges in this study were constructed to replace timber structures which were on the point of collapse, or which had done so already, having served sixty years or more. The timber bridge crossing Cattai Creek in the Hawkesbury region, for example, met its demise through attack by teredo worms[34], and was replaced by the current concrete beam bridge in 1946. The more usual story along the Princes Highway was severe damage or even complete destruction of timber bridges by flood. In other cases on the South Coast, bridges constructed in the late nineteenth century were just no longer appropriate for the traffic demands being placed upon them.

The bridge over Sheas Creek, otherwise known as the Alexandra Canal, in the Botany area was constructed to replace a lift span bridge built in 1895. Canal Road - Ricketty Street on which the crossing is located had become a busy thoroughfare by the mid 1930s as industry in the Botany area continued to grow, and the bascule lift span of the 1895 track span type bridge had a narrow carriageway, only capable of accommodating a single lane of traffic. As visibility on the approaches to the bridge was poor, traffic crossing the canal from either direction frequently met on the bridge, necessitating the backing up of one of the lines of vehicles.

The historical significance of some of the bridges in the study group is enhanced by physical evidence of older structures. The remains range from a few cut-off timber piles, such as those directly under the Poisoned Water Holes Creek Bridge on the Sturt Highway, to more substantial remains, such as the two abutments and one pier footing adjacent to the Mummel Brudge over the Wollondilly River on the Goulburn – Grabben Gullen Road.

Mummel Bridge (RTA Bridge No 6677) Old abutment

Concrete pier footing with base timber

A small group of bridges within the study set combine reinforced concrete beam decks from the period 1920-1948 with abutments and piers of an earlier era. The Hawkesbury River Bridge at Windsor was initially opened in 1874, consisting of iron piers filled with mass concrete, with a timber deck supported by hardwood girders. The deck was raised eight feet in 1896, with the extension of the iron piers. In about 1920 the current concrete beam deck was added. Thus the history of that bridge is a lot longer than the history of reinforced concrete beam bridges in NSW.

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[34] RTA General File 91.1537, Correspondence 5-31 December 1935

Hawkesbury River (RTA Bridge No 415) Cast iron caissons

Yellow Rock Bridge (RTA Bridge No 790) Mass concrete wall piers

Bowning Creek Bridge (RTA Bridge No 6474) Stone wall pier

Yellow Rock Creek Bridge at Albion Park [RTA Bridge No. 790] currently has a concrete beam deck, constructed in 1940, supported on mass concrete piers constructed in the late nineteenth or early twentieth century, which earlier supported a timber deck. The Bowning Creek Bridge at Bowning [RTA Bridge No. 6474] similarly incorporates stone abutments and pier constructed in the 1880s and a concrete beam deck of c1930. Through their form as composite structures, this small group of bridges has the ability to demonstrate changing needs and standards through the adaptation of the older structure for continued use.

For the majority of bridges in the study group, their construction was associated with upgrades of state-managed roads under the Department of Public Works and subsequently the MRB and DMR. As stated above, most were constructed on or near the site of the previous crossing, but in some instances the logical development involved the construction of deviations which necessitated the replacement of a number of crossings. The Cockwhy deviation on the Princes Highway, for example, which contains the concrete beam bridges over Stephens, Cockwhy, Hapgood, Higgins, Middle and Backhouse Creeks (RTA Bridge Nos 737, 738, 739, 740, 741, 742), was constructed in the 1930s to improve travel time and safety on the Princes Highway between Termeil and the area to the north of Batemans Bay, and was the longest and most ambitious of the deviations on the Princes Highway at the time[35].

Woronora River (RTA Bridge No 152)

Against the general trend, a small number of the bridges in the study group were constructed on entirely new roads built for purposes related to the political or economic climate of the twentieth century. During World War Two priority was placed on providing and upgrading road links seen as strategically significant for military purposes. Harris Creek Bridge and Woronora River Bridge, were constructed under this imperative as part of the Heathcote Road link between the Holsworthy Army Reserve and the Princes Highway at Heathcote.

The newer, more flexible bridge technologies embodied in the study set provided higher speed alignments, smoother surfaces and wider carriageways; the character of the State's roads were changed. The beam bridges in the study group along with road improvements facilitated comparatively reliable, safe, comfortable and speedy travel which revolutionised motor transport in local areas, regions and, cumulatively, the State as a whole.

History has not stopped since the bridges in the study group were constructed. Traffic volumes and speeds have continued to increase across the 20th century and expectations of road infrastructure have continued to

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[35] DMR, 1976, pp 160-161

rise. These trends have had an impact on the number, form and status of beam bridges constructed in the period 1907 –1948. The growth in vehicle weights and increases in lane and shoulder widths have meant that many bridges built of reinforced concrete in the 1907-1948 period have already been replaced. It is therefore testimony to the success and resilience of the subject bridges that they still exist. That many have been widened or duplicated is a reflection of their flexibility to be incorporated in upgrades. Of those which have not been changed in width, many have had their original pipe or concrete railings replaced with guardrailing which has a better safety record in redirecting impacting vehicles. The bridges with all original features intact have thus become a minority, and one that is under pressure, particularly those outside urban areas where high transit speeds and narrow bridges compromise road safety.

Broughton Creek Bridge (RTA Bridge No 704) Widened two span bridge composite with abutment

Stapletons Bridge Albion Park (RTA Bridge No 881) showing original frames, centre, and widening frames

Of the bridges that have been widened, some have been done in a way which is visually sympathetic to the original structure and preserves opportunities for the viewing and interpretation of the original bridge, whereas other widenings have paid scant attention to issues of aesthetics or sensitivity to the original structure. The widening of Broughton Creek Bridge on the Princes Highway, seen above, is an example of a sympathetic widening, using cantilevers attached to the existing three beam bridge, as is the widening of Stapletons Bridge Albion Park where additional beams of similar form to the original were used for the widening.

1.6.3. The Bridge Planning, Design and Construction Process.

Many roads in the first decades of the Twentieth Century were susceptible to quick degradation during rain, and stream crossings were even more vulnerable. The priorities of the Public Works Department , Main Roads Board and then Department of Main Roads were set by a combination of long term goals for infrastructure improvement and the responses necessary to flood events and the like and to community action for improved roads. Community action was directed to achieving all-weather roads and bridges on locally essential routes. This action usually took the form of written dialogue with the local representative of the Department of Main Roads (or its predecessors), and in some cases, via Members of Parliament.

Several of the bridges in the study group were constructed due to pressing local needs, and at times under the pressure of energetic community lobbying. For example, the Cattai Creek Bridge, completed in 1946 was constructed partly in response to community agitation for a new, higher level bridge over Cattai Creek, which began in the mid 1930s, with the Cattai District Progress Association writing to the Department. The Sydney Morning Herald of 2 March 1938 ran a short article noting that when the low level timber bridge was submerged in flood, farmers were forced to take their milk supplies to the factory across the creek by boat. The timber bridge was also dilapidated and planning for the current bridge was commenced prior to 1940, but, according to the RTA file, was delayed by World War Two. Safe pedestrian use of bridges, particularly those providing access to schools has also been a significant issue in the planning of bridges, with decisions as to whether to provide a footway (and who should pay) and retrofitting of footways being well represented in the correspondence in the MRB and DMR files.

Once the need for a new crossing was established, the site was surveyed, soil investigations undertaken and the catchment area measured. This work was typically undertaken by DMR personnel or contractors working for them. Bridges were typically designed by the Bridge Section in Sydney, with construction being undertaken through divisional offices. Construction was either by the Department's own work force (so-called day labour) or let out by tender to private contractors. Many local contractors were engaged. Irrespective of contractual arrangements, the majority of input was labour and the supply of materials, much of which was available locally – all assisting the local economy.

Bridge building is a specialised and highly skilled trade. Several generations of bridge builders were involved in the construction of the bridges in the study group. Construction in the period under study had certain salient features that made the builders a particular kind of community in an unusual workplace. The workers were often accommodated in camps due to the on-site pouring process which, when concrete was mixed by hand, was a slow, labour-intensive activity, and one which could not be suspended at convenience but which had to reach pre-designed construction joints. The study period saw an increasing mechanisation of the road and bridge construction process with petrol driven mixers replacing hand mixing of concrete for example.

Concrete mixer 1947 – Cockle Creek railway bridge (Photo Max Broadbent)

The construction of bridges often necessitated the bridge gang setting up camp in the neighbourhood. Mrs Jessie Johnston (nee McGregor) of Brogo remembers crossing the bridge over Alsops Creek every day to get to school. She remembers the construction of the new concrete bridge in 1929, chiefly because the bridge gang is suspected of poisoning her much loved old dog, which used to visit their camp and eat any unguarded food.[36]

The elaborate construction process was vulnerable to interruption by flood, and the economic exigencies of the time. More than one contractor was forced to relinquish the contract with the bridge still incomplete. The construction of Middle Creek Bridge No. 1 on the Wakehurst Parkway in Sydney's north by contractor Peter Koshemakin of Ulladulla was initially delayed by the difficulty of obtaining requisite materials on time and "the acute shortage of labour', due to the shortages of the early years of World War Two. At the end of March 1942, with footings prepared and at least one abutment completed, floodwaters washed away the timber falsework in place for construction of the bridge, and due to the losses incurred thereby, the contractor found himself financially unable to complete the work. The Department approached A.T.B. Anderson & Sons, who had just completed the construction of the nearby No. 2 bridge over Middle Creek and had also won the contract for the Deep Creek Bridge further to the north, to finish the job.[37]

Entire routes were constructed in the aftermath of the Depression in order to stimulate the economy and generate employment. Unfortunately, even the Board was affected by the economic woes in the depths of the Depression and unemployment relief works which carried 2000 people in 1929 (out of a total workforce of 4000) was curtailed completely by 1931, leaving only 1000 in jobs. By 1933 the number employed by the Board was back up to 3000, and in the mid 1930s relief works aimed directly at using unemployed labour included sections of the Princes Highway including the Cockwhy Range deviation, which contains the bridges over Stephens, Cockwhy, Hapgood, Higgins, Middle and Backhouse Creeks (RTA Bridge Nos 737, 738, 739, 740, 741, 742).[38]

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[36] **Correspondence, Bega Valley Historical Society, 2004**

[37] **RTA File 479. 1351, RTA File 479. 11736**

[38] The Roadmakers A History of Main Roads in New South Wales, Department of Main Roads NSW, 1976 pp160-161

1.6.4. The Construction Process and Visual Evidence of Construction in the Fabric of the Bridges

All of the bridges in the group bear evidence of the construction processes characteristic of their period. They are all cast-in-situ structures, involving the pouring of the concrete into a mould (formwork) supported on a scaffolding of falsework on the construction site. The majority of the bridges in the study group used timber formwork, which was eventually phased out by large sheets of formply. These developments left their imprint on the finished work. The beam design required complex formwork, particularly where the beams incorporated tapered or curved profiles, and where the bridge was built on a curve or a skew. Therefore, a team of skilled carpenters was necessary for the construction of each bridge.

Middle Creek No 1 (RTA Bridge No 146) Complex shapes using timber formwork

Middle Creek No 1 Remnant timber piles used for formwork support

Falsework used to support the formwork was originally made from timber, with concrete footing pads for this still visible under some bridges. (While this timber falsework was eventually replaced by standardised steel frames, there is no evidence of the transition). Within the concrete, the reinforcing steel had to be supported above the formwork to provide sufficient cover of concrete to prevent corrosion of the steel. This has been achieved by a variety of means over the years, with most work of the period being supported on small cubes of concrete referred to as Aspros. The marks of many of these can be seen on the undersides of bridges in the study group. Later, bar chairs were made from steel wire, then tipped with plastic, and finally made completely from plastic. These changes have reflected sometimes poor performance of these systems which, when they allowed the ingress of moisture to the steel, triggered corrosion.

Wandandian Creek (RTA Bridge No 723) This sturdy high level structure was erected in 1929 replacing a set of three low level timber bridges vulnerable to flood. As well as motor traffic, the bridge was used by bullock teams dragging logs to the Wandandian Sawmill

1.6.5. Relationships with Communities – using the bridges, and their place in the social and economic landscape.

Bridges represent a substantial and an essential part of the assets of the community. Of the bridges in the current study, the majority are on routes carrying high levels of goods and services, and their disappearance would bring much of the State to a halt. The cohort of bridges comprising the study group have a diverse set of relationships with the community. Some are in suburban Sydney or Wollongong, others in regional centres or small towns and some on long stretches of highway. As evidenced by replies from local historical societies, some bridges have been created and satisfactorily performed a function while remaining almost totally unnoticed, or have been simply experienced as part of general road improvements. Others provided much relief to locals at the time of construction, alleviating the stress of being stranded in floods or having part of the town cut off.

Burrangong Creek Bridge, Young (RTA Bridge No 6427).Shopping precinct in background and Information Centre on right

A small number of bridges in the study set have been connected to a community's sense of pride or identity. Burrangong Creek Bridge, now the Sarah Musgrave Bridge at Young is one such. The "Young Chronicle" gives an account of the opening of the bridge in early November 1932. The Mayor, Ald. Prescott presided over the proceedings, welcoming the Minister for Local Government, Mr Jackson, Commissioner for Transport, Mr Newell, and dignitaries from surrounding centres. The new bridge was heralded as a symbol of Young's progressive spirit and wise administration by Mr Jackson who said that, "the spirit of progress was exemplified by their doing away with the old and supplanting it with the new". The Minister cut a ribbon at either end of the bridge with a pair of gilt scissors. The opening was attended by a "huge crowd" who were eager to cross the bridge on foot and souvenir pieces of the ceremonial ribbon [39]. The first car to cross after the ribbon had been cut was a Chevrolet driven by Mrs Cyril Robertson of "Barwang", with her two children and the Town Clerk, Mr G S Sparks as passengers. The *Young Witness* newspaper noted that the main girders and piers were of heavy construction and would withstand great weights and great pressure from floods respectively, and that everybody in the town for the opening was full of admiration for the strength, durability and attractive finish of the newly completed bridge[40].

1.6.6. Visual Impact in the Landscape

A large proportion of the bridges in the study group are, by the nature of their scale and design, inconspicuous and unobtrusive, particularly from the roadway. Many are only discernable to the passing motorist by the presence of a signpost identifying the waterway, and a length of guardrail protecting the drop on either side. The bridges in the study group which retain their original steel pipe or concrete handrailings are much more visually distinctive from the roadway, the railings indicating their vintage.

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[39] **The Young Chronicle, Municipal Jubilee Number, 4 November 1932**

[40] **Young Witness Newspaper, 13 January 1932**

Haslams Bridge (RTA Bridge No 307) Original reinforced concrete railings

Harris Creek Bridge (RTA Bridge No 500) Pipe railings with concrete endposts

Croobyar Creek Bridge (RTA Bridge No 730) Retrofitted Thrierail guardrailing

In contrast to steel or timber and truss bridges which enclose the motorist and declare their structural form above deck level, for many bridges in the study group it is necessary to leave the carriageway and in some instances climb fences before the actual structure of the bridge can be viewed. An exception is the Tuena River Bridge, with a through-girder design, featuring edge beams which also form the bridge parapet or sidewall. The girders are robust structural members with enlarged top flange areas, thinner side walls with vertical ribs aligning with the cross beams, and bottom flange enlargements. The girders of the two central spans have an attractive curved profile.

Tuena River (RTA Bridge No 6401)

Ten Mile Creek, Holbrook (RTA No 5444) In town centre with model rail track beneath.

Hawkesbury River (RTA Bridge No 415) Viewed from riverbank parkland

A small number of bridges in the study group, however, have settings facilitating views of the bridgeworks. For example, Prouts Bridge in Canterbury has public parkland adjacent on both sides, and a cycleway passing underneath the bridge. Similarly, Burrangong Creek Bridge and Ten Mile Creek Bridge have public areas adjacent to, and underneath them. All three bridges have landmark qualities, forming gateways to the localities to which they facilitate road access, to Canterbury centre, and to the regional centres of Young and Holbrook respectively. Some of the bridges in the study group are impressive in scale and facilitate views to the waterways and valleys they cross. The Hawkesbury River Bridge at Windsor and the Woronora River Bridge are the longest bridges in the study group at approximately 143 metres and 125 metres in length respectively.

Both have landmark qualities because of their size and place in the landscape, the Hawkesbury River Bridge crossing the most impressive watercourse in the Sydney area, and the Woronora River Bridge soaring across a steep rocky gully in spectacular sandstone woodland country. The Hawkesbury River Bridge, Fullers Bridge and Lane Cove River Bridge (Northbound) both crossing the Lane Cove River, cross navigable watercourses and form landmarks from the water as well as the road.

Diggers Creek (RTA Bridge No 6201) Simple curved soffit

Croobyar Creek (RTA Bridge No 730) Complex curvature

Concrete beam bridges in general are the outcome of a process which has maximised function by minimising the complexity of form, resulting in simple clean construction lines. However, the study group includes a great range of minor variations on the basic beam designs, and a substantial proportion of the study set demonstrate some attention to aesthetic considerations on the part of the designers. The curved beam profile characterising many of the bridges has a simple but pleasing effect on both the small scale and larger bridges. The curved beam soffits of the single span Diggers Creek Bridge, present a modest but appealing form sympathetic to the spectacular Snowy Mountains landscape in which the bridge is situated. Croobyar Creek Bridge on the Princes Highway makes extended use of curved forms in its beams, crossbeams and headstocks, the entire bridge is built on a curve and crossfall, which emphasises the curved form further.

Many of the bridges enhance the simple, clean lines of the beam form with detailing of a broadly classical, art deco or modernist style. Such detailing renders these bridges visually distinctive as structures from the first half of the twentieth century. The advent of prestressing in more recent decades has resulted in the commodification of the smaller classes of bridges to the point where prestressed concrete planks are ubiquitous, and detailing of decks incorporates standard details, leaving bridges with little individuality. Paradoxically, prestressing, particularly in the form of post-tensioning, has also opened freedoms in design never available in reinforced concrete, and there are many newer structures of this form bearing testament to the ongoing concern of designers with aesthetics, at least on larger scale and visible projects (of which footbridges are a good example).

Middle Creek Bridge (RTA Bridge No 147) Post art deco endpost

Wonboyn River Bridge (RTA Bridge No 6012) Bold straight and curved lines

Couria Creek Bridge (RTA Bridge No 5978) Individualised pier framing

Concrete Slab and Arch Bridges

Heritage Study of Pre-1948 Concrete Slab and Arch Road Bridges

2005

HISTORY OF CONCRETE SLAB AND ARCH BRIDGES IN NSW

1.1. Timeline of Reinforced Concrete

The following timeline summarises the history of the material now referred to as reinforced concrete. Its path to the form used in bridges in New South Wales up till 1948 represents one of the successes of the industrial age by bringing together physics, chemistry, engineering and innovation to produce a product that has given excellent service to the community. The timeline, of course, did not stop at 1900, and this report also records what has happened to the various bridges since then, and their current role in the infrastructure of the state.

REINFORCED CONCRETE TIMELINE

12,000,000 BC	Reactions between limestone and oil shale during spontaneous combustion occurred in Israel to form a natural deposit of cement compounds. The deposits were characterized by Israeli geologists in the 1960's and 70's.
3000 BC	Egyptians used mud mixed with straw to bind dried bricks. They also used gypsum mortars and mortars of lime in the pyramids.
7th to 2nd C BC	Chinese used cementitious materials to hold bamboo together in their boats and in the Great Wall.
800 BC	Greeks, Cretans & Cypriots used lime mortars which were much harder than later Roman mortars.
300 BC	Babylonians & Assyrians used bitumen to bind stones and bricks.
300 BC - 476 AD	Romans used pozzolana cement from Pozzuoli, Italy near Mt. Vesuvius to build the Appian Way, Roman baths, the Colosseum and Pantheon in Rome, and the Pont du Gard aqueduct in south France. They used lime as a cementitious material. Pliny reported a mortar mixture of 1 part lime to 4 parts sand. Vitruvius reported a 2 parts pozzolana to 1 part lime. Animal fat, milk, and blood were used as admixtures (substances added to cement to improve the properties.) Many structures still exist. Bronze cramps were used to reinforce masonry in the Colosseum.
1200 - 1500 The Middle Ages	The quality of cementing materials deteriorated. The use of burning lime and pozzolan (admixture) was lost, but reintroduced in the 1300's. Gothic builders in Northern France used iron ties and cramps. Damage due to rust spalling led to abandonment of the method.
17th Century	Claude Perrault used armature of embedded iron for long span architraves in his colonnade in the Louvre.
1678	Joseph Moxon wrote about a hidden fire in heated lime that appears upon the addition of water.
1779	Bry Higgins was issued a patent for hydraulic cement (stucco) for exterior plastering use.
1780	Bry Higgins published "Experiments and Observations Made With the View of Improving the Art of Composing and Applying Calcareous Cements and of Preparing Quicklime."
1793	John Smeaton found that the calcination of limestone containing clay gave a lime which hardened under water (hydraulic lime). He used hydraulic lime to rebuild Eddystone Lighthouse in Cornwall, England which he had been commissioned to build in 1756, but had to first invent a material that would not be affected by water.
1796	James Parker of England patented a natural hydraulic cement by calcining nodules of impure limestone containing clay, called Parker's Cement or Roman Cement.

1802	In France, a similar Roman Cement process was used.
1812 -1813	Louis Vicat of France prepared artificial hydraulic lime by calcining synthetic mixtures of limestone and clay.
1812-1824	The world's first unreinforced concrete bridge was built at Souillac, France by Louis Vicat.
1824	Joseph Aspdin of England invented Portland cement by burning finely ground chalk with finely divided clay in a lime kiln until carbon dioxide was driven off. The sintered product was then ground and he called it Portland cement named after the high quality building stones quarried at Portland, England.
1828	I K Brunel is credited with the first engineering application of Portland cement, which was used to fill a breach in the Thames Tunnel.
1836	The first systematic tests of tensile and compressive strength took place in Germany.
1849	Pettenkofer & Fuches performed the first accurate chemical analysis of Portland cement.
1849	Joseph Monier of France commenced producing concrete tubs for orange trees using wire reinforcing.
1851	A beam consisting of brickwork reinforced with hoop iron was displayed at the Great Exhibition.
1854	Patent 2293 by W B Wilkinson of Newcastle, England for concrete floor with network of flat iron bars or wire rope sagging near centre of span. Not significantly commercialised.
1862	Blake Stonebreaker of England introduced jaw breakers to crush clinkers.
1865	Mass, unreinforced concrete used for multiple arch Grand Maitre Aquaduct to convey water to Paris
1867	Joseph Monier of France patented reinforced concrete portable containers.
1867-72	Patents issued to Monier for reinforced concrete pipes and bridges.
1875	First reinforced concrete bridge built to Monier design at Chazelet Castle, France
1884-1891	Wayss & Freitag acquired patent rights and built 320 reinforced concrete arch bridges with spans to 40m.
1887	Wayss published “Das System Monier”, incorporating theory developed by K Koenen
1894	Experimental Monier arch on Parramatta Road, Burwood as culvert.
1896	Aquaducts over Johnstons and Whites Cks at Annandale by Carter Gummow & Co.
1896	Unreinforced arch bridge over Black Bobs Creek near Berrima by J W Park
1897	Windsor Bridge over the Hawkesbury River redecked using reinforced concrete beam and slab construction.
1899	The first reinforced concrete bridge built in Victoria: Anderson St Bridge, by Carter Gummow & Co
1900	The first reinforced concrete Monier arch bridge built in New south Wales: Reads Gully near Tamworth, by Carter Gummow & Co

Prime references:[1],[2].

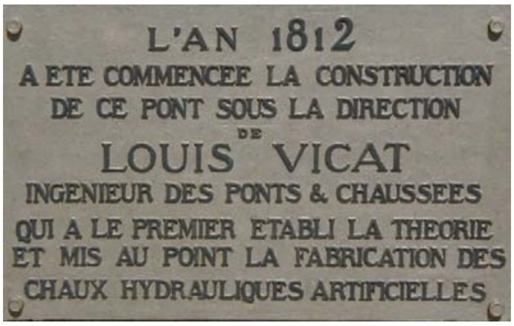
1.2. The Evolution of Concrete Technology – International Context.

The timeline above demonstrates the long path from the earliest uses of cementitious materials to the application of steel and concrete for the construction of bridges. Two keys were required to unlock the door: strong cements, and the means to carry tensile forces.

The Romans had used a cement sourced from the Italian town of Pozzuoli, mixed with lime, sand and water c.400BC – 476AD. This material was used as a binder in piers and arch spandrels, but also in mass footings.[3] In the following centuries the use of cement was largely lost although lime mortars (made by burning seashells for example) were common.

Louis Vicat in France, an engineer (Ingenieur des Ponts et Chaussees) initiated scientific studies of natural cements to reveal for the first time an understanding of the chemical properties of hydraulic (meaning it would set under water) cement. Between 1812 and 1824 he supervised the construction of a seven span unreinforced concrete bridge over the Dordogne River. Known as Pont de Souillac or Pont Louis Vicat, it has a total length of 180 m and utilised his artificial hydraulic lime.[4]

Pont de Souillac by Louis Vicat 1812-1824



Plaque on Pont de Souillac (source www.structurae.de)

In 1824 an artificial Portland cement was developed in England by Joseph Aspdin using a mixture of clay and limestone, calcined and finely ground. The use of these materials began to extend through the building industry as their utility became better appreciated. In 1828 Isembard Kingdom Brunel was credited with the first application of hydraulic cement to repair a breach in the Thames Tunnel which his father had designed.[5]

By 1865 unreinforced concrete had been used in France to build a mass concrete arch aqueduct, continuing to use the compressive strength of the concrete in exactly the same manner as stone which has been used in arch bridges for at least two thousand years. In this instance, it was used for a multiple arch aqueduct (Grand Maître Aqueduct), conveying water from the River Vanne to Paris.[6]

However, this use still reflected the limitations of masonry, which was its inability to carry tensile loads. Even when using stones with good tensile strength, the joints between blocks would not pass any dependable tensile forces. This shortcoming of masonry had been addressed in a variety ways over the centuries but with insufficient success to permanently change the way materials were used. China's oldest surviving bridge, of

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[1] "The History of Concrete" Materials Science and Technology Teachers Workshop, University of Illinois. Website //matse1.mse.uiuc.edu/~tw/concrete/hist.html

[2] International Database and Gallery of Structures www.structurae.de

[3] "Context of World Heritage Bridges" A Joint Publication with TICCIH, 1996 by Eric DeLony www.icomos.org/studies/bridges

[4] International Database and Gallery of Structures www.structurae.de

[5] "The History of Concrete" Materials Science and Technology Teachers Workshop, University of Illinois. Website //matse1.mse.uiuc.edu/~tw/concrete/hist.html

[6] "The History of Concrete" Materials Science and Technology Teachers Workshop, University of Illinois. Website //matse1.mse.uiuc.edu/~tw/concrete/hist.html

open spandrel arch construction, is the Zhaozhou Bridge (c AD 605), attributed to Li Chun and located in Hebei Province south-west of Beijing. Its thin curved stone slabs were joined with iron dovetails so that the arch could yield without collapsing.[7] This articulation allowed the bridge to survive the movements of abutments bearing on spongy, plastic soils, and also the effects of moving traffic loads. In Europe, bronze cramps had been used by the Romans in stone masonry in such structures as the Colosseum in Rome.[8] From the 12th Century, gothic builders used iron ties and cramps in cathedral construction. Unfortunately, damage in the form of rust spalling led to the abandonment of the method. In the 17th Century, Claude Perrault depended on an armature of embedded iron to achieve the long span architrave of his colonnade in the Louvre, Paris. The French-born engineer and innovator Marc Isembard Brunel (1769-1849) experimented with reinforced brickwork in 1832; and a beam of hoop-iron reinforced brickwork was displayed at the Great Exhibition of 1851. However, none of these approaches addressed the problem of corrosion of iron which increases its volume by a factor of 6 (causing bursting or spalling of material around it), not to mention the loss of strength as the iron turns to iron oxide (rust).

Joseph Monier 1823-1906
(source wwww.structurae.de)

The solution to this problem came from an unexpected source. In 1867, a French gardener, Joseph Monier was granted a patent for cement flower pots strengthened by iron-wire mesh embedded in the concrete and moulded to curvilinear forms. He had begun making such pots in 1849.[9] During this period to 1867 several other patents were granted to other innovators including: in 1848 for a reinforced concrete boat; in 1855, for the use of iron in combination with cement as a substitute for wood; and in 1854, for a concrete floor with a network of flat iron bars or wire rope. While Monier was not the first to put cement and steel together, he was the first to trigger its use in bridges. He was granted a patent in 1873 for the construction of bridges and footbridges made of iron reinforced cement. In 1875 he built the world's first reinforced concrete bridge, a four beam footbridge of 13.8m span and 4.25m width at the Castle of Chazelet, Saint-Benoit-du-Sault, Indre, France.[10] (By way of context, in the same year patents were taken out for the electric dental drill and blasting gelatin!) As he was not an engineer in a country which had a strong engineering heritage, (the Ecole Nationale Des Ponts et Chaussées was established in 1747) he was not permitted to design or build bridges for general public use. He therefore on-sold his patents in 1884 to German and Austrian contractors Wayss, Frietag and Schuster. Interestingly, the history of Wayss[11] suggests that they obtained the patent rights gratis, perhaps evidence of a lack of business acumen which ultimately led to Monier dying a pauper in 1906. Wayss, Frietag and Schuster built the first commercial reinforced concrete bridges in Europe: the Monierbrau footbridge of 40 m span in Bremen in Germany, and the Wildegg Bridge with a span of 37 m in Switzerland. It is reported that by 1891 they had built 320 arch bridges.[12]

As part of the process of developing reinforced concrete design, Wayss initiated strength testing of this new combined material, and had K Koenen develop a system of computation. This was published in 1887 as "Das System Monier", and incorporated the following principles:

- Steel alone took the tensile loads
- Transfer of force to the steel from the concrete took place through adhesion

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[7] "Context of World Heritage Bridges" A Joint Publication with TICCIH, 1996 by Eric DeLony www.icomos.org/studies/bridges

[8] "A note on the history of reinforced concrete in buildings" by S.B. Hamilton HMSO London 1956

[9] "A note on the history of reinforced concrete in buildings" by S.B. Hamilton HMSO London 1956

[10] International Database and Gallery of Structures www.structurae.de

[11] International Database and Gallery of Structures www.structurae.de

[12] "A note on the history of reinforced concrete in buildings" by S.B. Hamilton HMSO London 1956

- Volume changes in both materials due to temperature could be assumed to be approximately equal
- For calculations of bending, the neutral axis was assumed to be at the mid-depth of the section

In 1890, Paul Neumann, Professor at the Technical School of Brunn published a memoir on calculation using Monier construction in which he corrected the location of the neutral axis. This basically put the design of reinforced concrete into the hands of general civil engineers. This remained the theoretical basis for design until the middle of the 20th Century, when design based on ultimate strength criteria began to displace elastic design principles.

Pont Camille de Hogues (Pont de Châtellerault) 1900 First Heritage ranked reinforced concrete bridge. (source www.structurae.de)

Whilst the bridges of Wayss et al were the first of the genre, the period saw a proliferation of patents and applications for reinforced concrete. These took advantage of improvements in available cements and delivered structures considered to have enhanced features including fire and corrosion resistance, and freedom of form. Reinforced concrete began to be widely used in construction of civil works and then for commercial buildings.

The first firm to market reinforced concrete bridges internationally was formed by Frenchman Francois Hennebique who also held various patents for improvements to the art. His bridge at Châtellérault in 1900, an item of World Heritage significance under UNESCO's criteria, remains one of the first notable reinforced concrete arch bridges in the world, with a central span of 52m and two side spans of 40m.[13]

Outside Europe the reinforced concrete bridge began to spread, but sporadically. The first known reinforced concrete bridge in the USA was an arch built in Golden Gate Park, California in 1889.[14] New Zealand built several small footbridges in the Otepuni Gardens in Invercargill in about 1899 before their first road bridge in George Street Dunedin was constructed in 1903.[15] The bridge claimed to be the oldest in the UK is Chewton Glen near Milton in Hampshire, built in 1900.[16]

Otepuni Gardens footbridge c1899 (source Bridging the Gap by G Thornton)

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[13] "Context of World Heritage Bridges" A Joint Publication with TICCIH, 1996 by Eric DeLony www.icomos.org/studies/bridges

[14] "A Survey of Non-arched Historic Concrete Bridges in Virginia Constructed Prior to 1950" by A.B. Miller et al Virginia Transportation Research Council July 1996

[15] "Bridging the Gap Early Bridges in New Zealand 1830-1939" by G. Thornton, published by Reed

[16] www.hants.gov.uk/environment/bridges Bridges in Hampshire of Historic Interest

1.3. The History of Reinforced Concrete Bridges in the Context of New South Wales

1.3.1. Introduction

Bridging streams was one of the first public works carried out in the fledgling penal colony of Sydney. The Tank Stream was spanned by a bridge made from local timber, in the first year of European settlement, at the time, *"a gang of convicts were employed in rolling timber together to form a bridge over the stream at the head of the cove".*[17]

Lennox Bridge 1880s
(Source Mitchell Library scanned from Pictorial Memories Blue Mountains)

This set a pattern which was to continue into the twentieth century – of using the strong, plentiful, straight local hardwoods for bridge construction over streams. Larger rivers were crossed by punts or ferries. Although during the 1810s Governor Macquarie set his sights higher, and triggered a period of excellence in public works, no bridges of his period remain. The oldest surviving bridges are of stone arch construction over Lapstone Creek in 1833 and over Prospect Creek at Lansdowne in 1836, both by David Lennox. However, the vast majority of bridges built over the following eighty years were of timber. These were initially simple structures using timber for piers and abutments, with round logs forming the stringers of the deck, and topped with timber planking, all connected using iron bolts and spikes.

1.3.2. The Colonial Period

During the nineteenth century the need to span larger crossings, and to avoid piers in the water which degrade quickly and form an obstruction to flood debris, led to the development and adoption by the 1850s of a range of truss designs. These were typically named after the designers who developed their geometry, immortalising Allan, Warren, McDonald, Pratt and Howe amongst others. While Percy Allan was an Australian (Chief Engineer for National and Local Government Works, Public Works Department), they were not all local engineers (Pratt was an American for example). Information on the latest bridge design tended to spread fairly rapidly through the worldwide engineering community. Adoption of new ideas was, however (and remains) a slower process, being driven by a diverse set of parameters including cost, material availability, site suitability and various pragmatic issues such as individual preferences, resistance to change, and the cost of preparing new designs.

As the century wore on, iron in its various forms became more available and its use in bridges increased. Its ability to carry tensile loads led to truss forms wherein timber in the truss tension diagonals was replaced by wrought iron and then steel rods. Although complete iron bridges had been built elsewhere from the late eighteenth century (Ironbridge 1779), it was not till 1851 that an all metal superstructure was erected in New South Wales over Wallis Creek at Maitland. Subsequent bridges included the Prince Alfred Bridge over the Murrumbidgee River at Gundagai in 1865 having three continuous wrought iron spans, the Denison Bridge over the Macquarie River at Bathurst in 1870 using iron from the Fitzroy Iron Works at Mittagong, and Iron Cove and Parramatta River bridges in Sydney in 1882 and c1883 respectively. Complexity of steel structures increased rapidly, with swing, bascule and lift opening spans becoming common, with the technology

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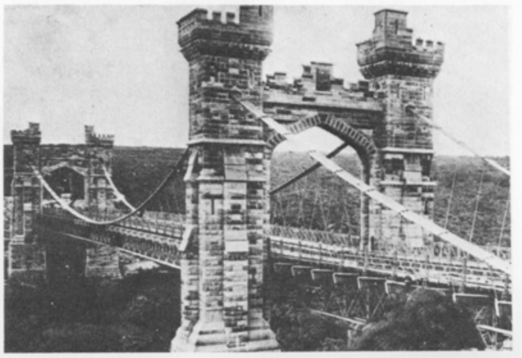
[17] The Roadmakers A History of Main Roads in New South Wales, Department of Main Roads New South Wales, 1976

extending to suspension bridges (Hampden Bridge, Kangaroo Valley 1898 and Northbridge 1892).[18]

Concrete saw its first role in bridges in New South Wales through the "back door". It was found to be a suitable material for filling the insides of cast iron pier caissons and the like, providing a filling which was not only strong and stable but also protected the iron from corrosion due to its alkalinity. It also began to make cameo appearances in the form of mass concrete for abutments. This actually revived a role concrete had filled for the Romans two thousand years earlier.

The completion of this suspension bridge in the 1890's led to the naming of Sydney's suburb, Northbridge.



Northbridge (source The Roadmakers)

With the dominance of German speakers in the commercialisation of reinforced concrete bridges in the late nineteenth century it is not surprising that this link brought the technology to Australia. W J Baltzer, a German immigrant working for the New South Wales Public Works Department maintained contact with his brother in Germany, and through that link, awareness of the emerging technology. In 1890 he travelled to Germany to gather information on this new form of bridgebuilding. But on his return he was unsuccessful in interesting his superiors in the technique and ultimately joined several businessmen to obtain licences through Wayss to cover the Australian Colonies.[19]

Their company, Carter Gummow & Co, built several small trial structures, apparently one of these being a culvert under Parramatta Road at Burwood in 1894.[20] Unfortunately, it is unclear if this structure is still extant. The current main crossing has a flat soffit and the semi-arched connection to an upstream circular pipe is of rough construction unlikely of a trial structure built to impress potential users.

Entrance to culvert under Parramatta Road Burwood

Arched connection from slab culvert to circular pipe under footpath

Carter Gummow & Co subsequently obtained contracts to build two large arched sewage aqueducts over Johnstons Creek and Whites Creek in Annandale.[21] Completed in 1896 they remain as probably the earliest reinforced concrete bridge-like structures in Australia.

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[18] The Roadmakers A History of Main Roads in New South Wales, Department of Main Roads New South Wales, 1976

[19] John Monash Engineering Enterprise Prior to World War I Introduction of Monier concrete to Victoria, Australia http://home.vicnet.net.au/~aholgate/welcome.html

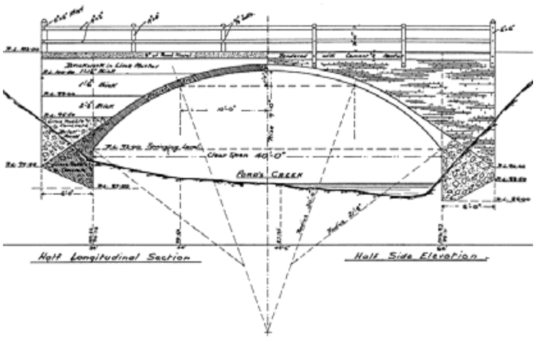
[20] Some Notes on the History of Concrete Bridges in N.S.W. by L.H. Evans Unpublished manuscript, stamped March 1986, held by RTA library, Parramatta

[21] John Monash Engineering Enterprise Prior to World War I Introduction of Monier concrete to Victoria, Australia http://home.vicnet.net.au/~aholgate/welcome.html

Johnstons Creek Aqueduct, Annandale

Whites Creek Aqueduct, Annandale

Baltzer became the Chief Engineer of Carter Gummow and in this role began promoting the technology. He spoke in 1897 to the Engineering Association of NSW, and the company held a stand at the Engineering and Electrical Exhibition in Sydney, gaining coverage in the Building Mining and Engineering Journal.



Monier arch, Fords Creek, Victoria(sourcehttp://home.vicnet.net.au/~aholgate)

Monier arch construction, Victoria. (Source:State Library of Victoria)

In the same year Gummow and W C Kernot, Professor of Engineering at the University of Melbourne jointly mounted an exhibition on the subject in Melbourne. The partnership of John Monash and Joshua Anderson, which had formed in 1894, obtained from Gummow sole rights to the Monier patent in Victoria. In 1899 Anderson St Bridge was built by Carter Gummow & Co and then the Monash/Anderson partnership constructed two Monier arch bridges, at Fyansford and Wheelers Creek in 1900. Several others followed. In 1901 one of their bridges, Kings Bridge at Bendigo, collapsed whilst being load tested,[22] ultimately bringing the partnership down with it, but not before they had built a total of 15 bridges in the period 1899-1903. The Bendigo bridge was a heavily skewed arch. It collapsed under an unusually severe test load of a steamroller

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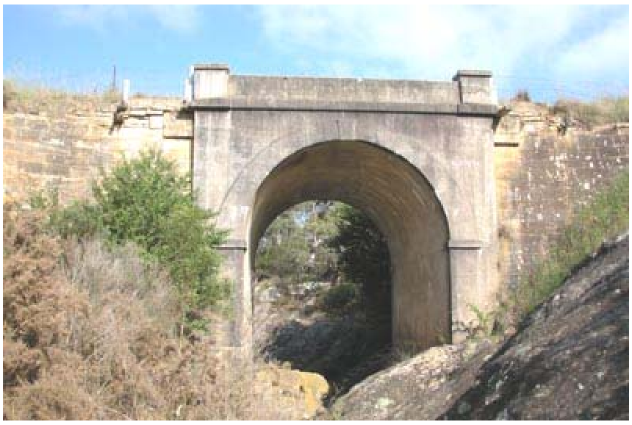
[22] John Monash Engineering Enterprise Prior to World War I Introduction of Monier concrete to Victoria, Australia History of King's Bridge Bendigo http://home.vicnet.net.au/~aholgate/jm/texts/kingshist.html

Kings Bridge collapse during load test by steam and traction engines – both visible (source http://home.vicnet.net.au/~aholgate/jm/)

back to back with a steam traction engine, killing one man. The partnership was exonerated by the coroner when Professor Kernot of the University of Melbourne showed that accepted theory (as set forth in W J M Rankine's texts) greatly underestimated the stresses in skewed arches - by a factor of as much as four. Monash went on to establish the Reinforced Concrete and Monier Pipe Company, and progressively moved into beam type bridges rather than the arch concept which had proved so troublesome.

Returning to New South Wales, the oldest existing concrete road bridge was constructed for the Public Works Department by J W Park of Gladesville in 1896 over Black Bobs Creek on the Hume Highway near Berrima.[23] Like the Pont de Souillac, it was unreinforced, having a 9.14m span and a width of 8.84m. It remained in service until the Highway was rerouted in 1971, despite the concrete having been made from low strength sandstone aggregate. It has been said in the RTA that the bridge was, in fact, detailed with exposed stone to avoid problems from those who were nervous about the new technology of concrete. Whilst this bridge is no longer in service, it remains in the hands of the RTA and there are current plans to improve its accessibility from an adjacent rest area, and install appropriate heritage signage.



Black Bobs Creek Bridge, old Hume Highway alignment. Unreinforced concrete arch

Whilst on the issue of unreinforced arches (i.e. the form leading to reinforced concrete arches) it should also be mentioned that brick and stone arches were also a very significant bridge form, not so much for road bridges as for rail. The spread of an extensive rail network throughout New South Wales saw a large number of brick arches built, ranging in size from modest culverts to large multispan structures such as those visible west of Lithgow. One of these which has come into the RTA's portfolio is the sandstone multi-span arch over Knapsack Gully at Glenbrook. Originally built in 1865 as part of the centre leg of a zig-zag rail link up the eastern escarpment of the Blue Mountains, it consists of 7 arches, reaching a height of 38m at the centre. It was designed by John Whitton, engineer-in-chief of the Railways, and referred to as his masterpiece.[24]

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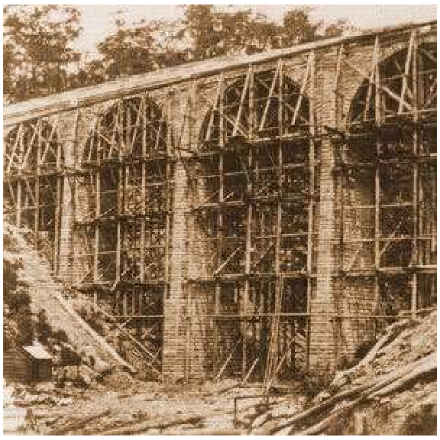
[23] Some Notes on the History of Concrete Bridges in N.S.W. by L.H. Evans Unpublished manuscript, stamped March 1986, held by RTA library, Parramatta

[24] The Roadmakers A History of Main Roads in New South Wales, Department of Main Roads New South Wales, 1976

Lapstone masonry arch bridge
(Photo NPB Photographics)

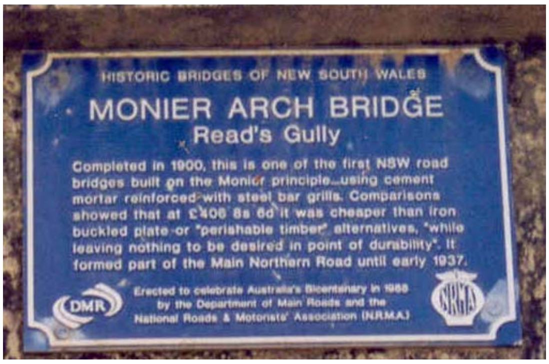


Lapstone Bridge during construction
(source http://info.mountains.net.au/rail/lower/lapstone.htm)

Abandoned in 1913 when the rail line was rerouted to avoid the delays of the zig-zag, it was widened and reopened in 1926 to carry the Great Western Highway. Another (brick) arch structure still in the RTA inventory was a brick arch built in 1840 over Duck Creek at Granville, servicing the Great Western Highway. A number of other masonry arches from the late nineteenth century are also still in service.

In 1900, six years after the trial culvert at Burwood, a Monier reinforced concrete arch was erected over Reads Gully on the Main Northern Road near Tamworth (presumably by Carter Gummow & Co who held the patent rights) at a cost of £406.8.6. The bridge served until it was replaced during a realignment of the New England Highway in 1937. It is now in the care of Parry Council. The Assistant Engineer for Bridges, Mr E M De Burgh mentioned in the Public Works Department Annual Report for 1900 that the Monier arch system would have been used more often if there had been more suitable sites.[25]

Reads Gully Bridge, Tamworth



HISTORIC BRIDGES OF NEW SOUTH WALES

MONIER ARCH BRIDGE

Read's Gully

Completed in 1900, this is one of the first NSW road bridges built on the Monier principle...using cement mortar reinforced with steel bar grills. Comparisons showed that at £406 8s 6d it was cheaper than iron buckled plate or "perishable timber" alternatives, "while leaving nothing to be desired in point of durability". It formed part of the Main Northern Road until early 1937.

Erected to celebrate Australia's Bicentenary in 1988
by the Department of Main Roads and the
National Roads & Motorists' Association (N.R.M.A.)

Plaque on Reads Gully Bridge, Tamworth

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[25] Some Notes on the History of Concrete Bridges in N.S.W. by L.H. Evans Unpublished manuscript, stamped March 1986, held by RTA library, Parramatta

Such a site was soon found at Richmond where the existing timber bridge was prone to damage during the frequent floods which submerged it, often with heavy loads of floating debris. Professor W. H. Warren of Sydney University acted as a consultant to the Public Works Department on the design which consisted of thirteen Monier style arches, two of 15.84m span and eleven of 16.45m. With a total length of 214.6m this 1905 structure was the longest reinforced concrete bridge in New South Wales for the next 25 years.

Bridge over Hawkesbury River at Richmond 1905 (RTA Bridge No 429)

Not far downstream from Richmond was a bridge of almost comparable proportions. Supported on cast iron caissons sunk a metre into rock, the Bridge over the Hawkesbury River at Windsor was originally opened in August 1874.

The original deck had been formed using 16 inch by 17 inch hardwood stringers topped with timber planking. In 1897 a new 143m deck of closely spaced reinforced concrete beams was opened. The new deck was apparently installed when the level of the bridge was raised by 2.4m to its present level by the addition of extra cast iron stub column pairs connected by reinforced concrete headstocks. Thus the honour of the oldest extant reinforced concrete bridge deck in New South Wales rests with a renovated bridge – but one of substantial proportions.

Bridge over Hawkesbury River at Windsor Raised and redecked 1897 (RTA Bridge No 415)

1.3.3. Developments in the Twentieth Century

In support of the move to use reinforced concrete for local structures, Professor W.H. Warren, Challis Professor of Engineering at Sydney University and President of the Royal Society of NSW undertook research into the strength and elasticity of reinforced concrete utilizing local materials. Results of these investigations were published in the Journal of the Royal Society of NSW in 1902, 1904 and 1905.[26] Despite this supportive work, the number and scale of concrete bridges built in New South Wales over the next decade was small. Included were a concrete beam bridge at Rockdale in 1907, the slab bridge over Muttama Creek at Cootamundra (RTA Bridge No 6438) in 1914 and the beam bridge over American Creek near Figtree in the same year (now replaced), a similar bridge over Mullet Creek, Dapto of 1916 (now replaced), a concrete beam bridge at Throsby Creek Wickham and a slab bridge over Surveyors Creek at Walcha (RTA Bridge No. 3485), both completed in 1916. The bridge described as "the first true continuous girder reinforced concrete bridge" was Fullers Bridge across Lane Cove River, completed in 1918.(RTA Bridge No. 105)[27]

Mutttama Creek Cootamundra 1914 (RTA Bridge No6438)

Surveyors Creek Walcha 1916 (RTA Bridge No 3485)

These structures, with deck geometries having either flat soffits or beams, represented a logical step forward in the use of reinforced concrete. While the first applications promoted by the Monier patents were arched, this did not in fact, fully utilise the freedom of geometry that reinforced concrete was able to offer. In the traditional masonry arch, avoidance of collapse was achieved by keeping the line of compression within the stone or brickwork. With a reinforced arch the same thinking initially applied, but with the advantage that the reinforcement could accommodate any local bending effects (such as from concentrated loads from heavy wheels) by using the tensile capability of the concrete. However, these structures were still faced with placing filling on top of the arch to build an almost level surface for traffic, and this meant an overall heavy (and thus somewhat inefficient) structure. In centuries past this difficulty had been overcome by various stratagems, including horizontal cylindrical holes through the spandrels or building arch upon arch – as used in Roman aqueducts. Once designers of reinforced concrete began to use the material in other structures such as buildings, they developed designs which allowed flat slabs of reinforced concrete to carry loads in bending. By placing the reinforcing steel predominantly in the bottom of the slab at midspan, and bending it up into the top over supports (where the bending effect is reversed) they were able to place the steel effectively where the tension forces occurred. Progressively it was realised that by thickening the concrete into beams which spanned between piers, and leaving the slab thinner in between these (i.e. having a form similar to that of the Windsor Bridge deck), that good economies could be achieved. The logic contained in these early bridges was to persist with relatively modest changes until the introduction of prestressing in the 1950s.

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[26] W.H. Warren, ' Investigations in regard to the comparative strength and elasticity of Portland Cement Mortar and Concrete when reinforced with Steel Rods and when not reinforced'. *Journal of the Royal Society of NSW*, Vol. XXXVI, 1902, pp.290-313; 'Further Experiments on the Strength and Elasticity of Reinforced Concrete', *Journal of the Royal Society of NSW*, Vol. XXXViiI, 1904, pp.140-189; 'Reinforced Concrete, Paper III', *Journal of the Royal Society of NSW*, Vol. XXXIX, 1905, pp.49-64.

[27] Some Notes on the History of Concrete Bridges in N.S.W. by L.H. Evans Unpublished manuscript, stamped March 1986, held by RTA library, Parramatta

By the end of World War I there was the prospect of a substantial increase in both bridge building in general and in reinforced concrete in particular. In 1914 the Director General of Public Works stated that *"the increasing cost and difficulty in obtaining timber of suitable quality and dimensions for the large highway bridges determined me to adopt steel and ferro-concrete construction wherever practicable".* [28] In contrast with timber, the raw materials for reinforced concrete bridges: coarse aggregate, sand, cement and steel bars were becoming readily available. The other driver was the explosion of private car ownership and the dramatic growth in truck transport of goods.


Mulyandry Creek Cowra (Bridge No 4282) Note curved deck with crossfall to suit

The style of roads and bridges which had sufficed during the nineteenth century, wherein the road alignment and surface was subservient to the surroundings, was no longer acceptable for the higher vehicle speeds now emerging. Road design became a science in which the design speed dictated the minimum radius of vertical curves as well as horizontal ones. These were predicated on principles of safe stopping sight distances, and on limiting the lateral forces on vehicles. Previous rules, such as that mandated by the railways, that all overbridges must be at right angles to the rail line (to minimise soot effects from steam trains) began to be overturned, as were rules of thumb such as minimising the cost of bridges by making them straight and of minimum length (for example over rivers). Other parameters to evolve progressively during the Twentieth Century included the design weight of vehicles, the width of lanes, the provision of width to provide continuity with the shoulders of the roadway, and rules for impact resistance of railings. All of these have had their impact, not only on the design of new bridges but also on the continued appropriateness of existing structures and the need to modify them to maintain their level of service.

1.4. The Role of Government in Road and Bridge Expansion in NSW.

1.4.1. The Colonial Era

Prior to the granting of responsible government in the 1850s all authority and responsibility was exercised by the Crown's representative in the Colony of New South Wales, the Governor. Roads and bridges were constructed by decree of the Governor on the advice of his staff. These were the officers of the Colonial Architect's Branch of the Surveyor-General's Office. This system evolved at Federation into a structure containing three tiers of control: Federal, State and Local. Interfacing with this hierarchy was free enterprise, the entrepreneurial companies of which variously built roads and bridges for contracted amounts or were licensed to carry out works and collect tolls. The course of change through this process has been well documented in such works as *The Roadmakers*, and *Vital Connections.* During the period of interest for this current study, viz 1905 to 1948, many changes occurred. Leading to the period in question (and covering some of the earliest reinforced concrete works), the Department of Public Works (created in 1859) was put under the control of R Hickson as Commissioner in 1889 who separated the State into six divisions, each with its own Resident Engineer who reported to Divisional

David Lennox

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[28] Some Notes on the History of Concrete Bridges in N.S.W. by L.H. Evans Unpublished manuscript, stamped March 1986, held by RTA library, Parramatta

Engineers operating from Sydney. In 1895 the Roads, Bridges, Harbours and River Branches were placed under the control of one officer with the title of Engineer-in-Chief for Public Works, and Hickson was appointed to this position. In the following year he was also made Under Secretary for Public Works.

1.4.2. Key Bridge Design Personnel

The following table identifies many of the key engineers involved with the design or design management of bridges in NSW, with particular reference to the period under study. The list is provided to help readers understand the flow of engineers and managers who drove the design processes of the road bridge network. Where information has been available to link individuals to bridges, this has been identified. Unfortunately, in the majority of the bridges under study, little remains in the RTA files to identify the actual designers. Where original drawings (or copies thereof) are on file, the initials of designers are sometimes discernable and these have been acknowledged in the inventory.. However, the practice of not including the designer's full name on the drawings, and giving him recognition on the bridge itself, all conspire to hide the identity of the individuals who created the original designs.

Having said that, it should be recognised that bridge design, like many other areas of human endeavour, is generally not the work of one person alone, but the compilation of inputs from those who have gone before in developing earlier designs, of field personnel who gather data necessary for proper assessment of foundations, waterways etc, of peers carrying out design checking and drafting, and of management who ensure that all aspects are orchestrated efficiently and within overall budget constraints.

In the instance of slab and beam bridges in particular, the modest scale of most crossings has meant that designs became more or less standardised, with individual bridges being created by use of standard spans, piers and abutments. These standard designs tended to stay in use for some years until the march of progress, in the form of increased traffic design loads or improved material properties (such as concrete strength) meant that revision was warranted, leading to another standard design.

KEY NAMES IN BRIDGE DESIGN, NSW

Title	Name	Start Date	End Date	Significant Work
First *Superintendent of Bridges*	David Lennox	June 1833	1843	Lennox Bridge Lansdowne Bridge
Commissioner and Engineer-in Chief for Roads	W.C. Bennett	1862	1889	
Engineer-in-Chief for Public Works	R. Hickson	1889	1901	
Professor of Engineering, Sydney University	Prof W.H. Warren	1883	1925	Northbridge suspension bridge, Richmond Bridge
Bridge Modeller & Bridge Computer	H.H. Dare			Richmond Bridge
PWD Engineer	John A. MacDonald			MacDonald truss bridges
Chief Engineer for National and Local Government Works	Percy Allen	??	46 years	Allen truss bridges; Associated with more than 550 bridges
Chief Engineer, Sydney	Dr J.J.C. Bradfield	1891		Sydney Harbour

Harbour Bridge and Metropolitan Railway Construction, PWD	1867-1943	(Started with PWD) 1912	1932	Bridge
Supervising Bridge Engineer	E.M. De Burgh	1891 (?)	1900?	De Burghs Bridge, Lane Cove
Bridge Engineer (Transferred from Public Works)	Spencer Dennis	1928	1951	Promoted use of Reinforced concrete
Bridge and Designing Engineer	H.M. Sherrard	1926	1928	
Assistant Bridge Engineer	F.W. Laws	1935	1942	
Assistant Bridge Engineer	C.A.M. Hawkins	1944	1946	
Assistant Bridge Engineer	R.A.J. Thompson	January 1946	November 1946	
Assistant Bridge Engineer	A.J.Clinch	1946	1953	
Bridge design engineer	Vladimir Karmalsky	1930s	1950s	Bow-string arches
Bridge design engineer	A.T. (Sandy) Britton	1930s	1950s	Shark Ck, Hillas Ck (bow-string arches)
Bridge design engineer	A Halvorseth	1930s	1950s	Tuena River (through girder) Galston Gorge Bridge and others

Prime reference[29]

1.4.3. The Twentieth Century

With the turn of the century, significant political change occurred. The States combined (with the blessing of the Crown) to form a new country, the Commonwealth of Australia, in 1901. The increase in population also led to further pressure for decentralisation of power, and the 1906 Local Government Act transferred to shires and municipalities the responsibility for care and maintenance of local roads and other public works. This was funded partly by council rates which were based on the unimproved capital value of land, and topped up by grants from the State and Federal governments under a variety of funding arrangements. As a result of the handover, the greater part of the state's 48,500 miles of roads and bridges were passed over to the care of local government, and in 1907 the position of Commissioner for Roads was discontinued. Unfortunately, this change led to a decline in the amount of money actually spent on roads in general, and main roads in particular although a proportion of roads and bridges were declared National Works and were maintained by the Department of Public Works.

By the end of the First World War, the NSW roads were in a poor state with even national roads badly underfunded. In 1924, after years of haggling and politicking, the Main Roads Bill was introduced into the New South Wales Parliament and subsequently the Main Roads Board of New South Wales was created in 1925 with the powers to function as a State road authority, and with 12,840 miles of roads to care for. Within a year the Board was swamped with requests from councils eager to offload their road responsibilities, the cost of which had been escalating. Early planning reviews not only allocated funding to established roads, but also set in train plans for a dozen new roads linking areas of the state not well connected by the road system

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[29] The Roadmakers A History of Main Roads in New South Wales, Department of Main Roads New South Wales, 1976

which, until then, had grown like the proverbial Topsy. These new roads required new bridges, a number of which form part of the present study.

It was not until 1927, after almost three years of wrangling between the Main Roads Board and the Department of Public Works that a clear definition of the lines of responsibility was achieved. The Department of Public Works took charge of roads and bridges in the Western Division, and the Main Roads Board took responsibility for Main and Developmental Roads in the Eastern and Central divisions of the State. Matters relating to other roads, including interfaces with the councils, were placed with the Department of Public Works.

To rationalise the system of road classifications, all roads were reviewed in 1928 and new classifications of State Highways, Trunk Roads and Ordinary Main Roads were introduced. These changes had substantial implications for funding of the various roads, and thus of the councils who carried out much of the work. In the same year the Main Roads Board decentralised its road design and construction activities to regional headquarters in Glen Innes, Tamworth, Parkes, Queanbeyan, Wagga Wagga and Sydney. While it was feasible to set up road design teams in these offices, the high level of professional skill required for bridge design (and the more peaky nature of the workload) was seen as justification for keeping the bridge design team together in Sydney, at the Board's offices in Castlereagh Street.

More political machinations and funding skirmishes saw the Main Roads Board dismantled in 1932 and replaced by the Highway and Roads Transportation Branch of the Department of Transport. In the aftermath of a dogfight between the State and Federal governments (during which the funds of the State were garnisheed by the Commonwealth), the Department of Main Roads was created in 1933, a bureaucratic arrangement which lasted until 1989. These organisational changes occurred during (and perhaps because of) confronting times of economic depression and high unemployment.

From 1932, motor vehicle registrations grew at the astonishing annual rate of 48% in a period of 4% population growth and with a depressed economy. As the motor vehicle moved from being an unreliable and relatively slow contrivance to an essential high speed means of transport, new concepts for roads began to emerge, including multilane roads, grade separated intersections, speed limits, removal of level crossings, and, in the country, separation of roads from stock routes. Thus the focus changed from making the roads passable to making them safe and efficient. By 1938 the total length of roads covered by the Department was 24,643 miles. This was a boom period for the construction of simple, functional concrete bridges which embodied the new standards, to replace decrepit timber structures or flood prone open crossings on roads controlled by the Department. (Whilst not part of this study, the same pressures were also being felt at the local government level with respect to bridges on local roads. However, with lower levels of funding their inventory of bridges typically lagged behind).

With World War II looming, and then running from 1939-1945, external drivers impacted the development of roads and bridges over the final 10 years of the period under study. The decisions regarding which roads would be built and which bridges built or upgraded were made on defence criteria ahead of general traffic management issues. Key issues included the ability to move troops and military hardware rapidly from military facilities to strategic defensive locations. North-south lines of communication were seen as particularly important, with potential invasion expected from the north. Further downsides of the war included the diversion of funds and personnel away from non-strategic infrastructure. Contractors with bridges already committed to construction found difficulty getting tradesmen and materials to complete their works, and the Department was asked for extensions of contract times in many cases.

Coming out of the War, there was another hiatus as the community and bureaucracies refocussed. This meant another difficult period of limited access to equipment, materials and personnel even for urgent works, some of which had been held over from prior to commencement of hostilities. The War had seen a further jump in motor vehicle technologies and with it a new era of road planning began to implement more of the ideas regarding traffic management conceived in the 1930s, but not brought to fruition. The late 1940s thus closed out an era, to be replaced by a new world of freeways and prestressed concrete.

1.5. The Reinforced Concrete Bridge as an Element of Public Infrastructure – Social and Historical Significance

1.5.1. Introduction

Despite the arduous process required of Baltzer and others to get reinforced concrete bridges accepted as a valid medium, the social impact of these bridges during the twentieth century has been immense. From a standing start at the turn of the century, they achieved the status of preferred bridge form for small to medium spans, and were looked to to provide the flexibility that would allow greatest spans to be contemplated. They are now a ubiquitous part of the landscape, generally providing many years of troublefree service to the community and representing a substantial part of the bridge infrastructure of the state.

1.5.2. Bridges as Infrastructure

Bridge over the Dawson River at Cundletown (RTA Bridge No 1803)

Only two of the bridges in the study group are over major waterways – the Dawson and Hawkesbury Rivers. Here the bridges have played a major part in the development of important routes, replacing punts and less reliable lower level bridges. In doing so they have also become dominant features in the landscape and are perceived as important infrastructure items by the community. Most of the remaining bridges in the study group are more modest structures which cross minor waterways, many of which, especially in the western half of the study area, are dry for much of the year. However, their value as infrastructure should not be underestimated. These sites are characterised typically by various combinations of steep gullies, bogging sands, rapidly rising freshes or persistent flooding. These smaller bridges replaced open crossings, causeways, culverts or more maintenance-intensive and dilapidated timber bridges to create, along with road improvements, reliable, safe, comfortable and speedy transport which revolutionised motor transport in local areas, regions and, cumulatively, the state as a whole.

Bridges in the study group were built in a number of different infrastructural contexts. Several of the bridges were constructed due to local needs, and at times under the pressure of energetic community lobbying. The reliable carriage of goods is what the community looks for in its road and bridge system. The bridge over Swanbrook Creek near Glen Innes was finally built after years of transport hold ups whilst waiting for freshes to subside. (*Inverell Times*, 21st June 1921). Similarly, the *Lithgow Mercury*, 19th Nov, 1928 notes the opening of the Marrangaroo Creek bridge with some relief: 'There will … be no need in future for cars to wade through the river, the Bugbear of many local drivers…'. Safe pedestrian use of bridges, particularly those providing access to schools has also been a significant issue in the planning of bridges, with decisions as to whether to provide a footway (and who should pay) and retrofitting of footways being well represented in the correspondence. In several cases, the concrete bridges in this study were constructed to replace timber structures which were on the point pf collapse, or which had done so already, having served sixty years or more. The historical value of some of the bridges in the study group is enhanced by physical evidence of these older structures.

Old footing and headstock,

Previous pier timbers, Tyagong

Log protruding from

Eastern Creek Riverstone (RTA Bridge No 535) *Creek Cowra (RTA Bridge No 4080)* *abutment fill, Jeir Creek No 1, Yass (RTA Bridge No 6341)*

For the majority of bridges in the study group, their construction was associated with upgrades of state-managed roads under the Department of Public Works and subsequently the DMR. In some instances this involved the construction of deviations or new routes and necessitated the modernisation of a number of crossings. For example, slab bridges were constructed over Ugumjil, Bundara and Rays Creeks, within several kilometres of each other, in 1938/9 in conjunction with the improvement of the Newell Highway south of Dubbo. Such programmes often involved the combining of the construction of two or three bridges in a single contract.

Different times produce different priorities, and during World War II, this was manifested in providing and upgrading links seen as strategically significant for military purposes. The bridges on Heathcote Road (Williams Creek, and Deadmans Creek) were constructed under this imperative.

1.5.3. Visual Impact in the Landscape

The bulk of the bridges in this study are, by the nature of their design, inconspicuous and unobtrusive. Many are only discernable to the passing motorist by the presence of a signpost identifying the waterway, and a length of guardrail protecting the drop on either side.

Jeir Creek Bridges 1 and 2 suggest little to the motorist

This is in contrast to the steel, timber and truss bridges which enclose the motorist and declare their structural form above deck level. For most bridges in this study it is necessary to leave the car and in some instances climb fences before the actual structure of the bridge can be seen. Even then, the bulk of bridges are the outcome of a process which has maximised function by minimising the complexity of form, resulting in simple clean construction lines with little to attract attention. They may thus be summarised generally as successful infrastructure, providing community service for a minimum of capital cost and upkeep. Failures, particularly in the area of ongoing maintenance requirements, have also been identified in the study group, among them being the simply supported slabs which in many instances have cracked and been repaired repeatedly, yet are still carrying out their function.

Spring Creek Bathurst (RTA Bridge No1002) showing headstock and slab distress

Another subset within the study group are those bridges which have settings facilitating views of the bridgeworks. These include bridges with picnic grounds such as those at Swanbrook Creek west of Glen Innes and Deep Creek at Narrabeen Lake. Incidentally, both this bridge and the Bridge No 3 over Middle Creek were designed with the expectation that boaters would row under them as part of the recreational uses of the Narrabeen Lake. Two bridges (Belubula River flood Channel at Canowindra and Dawson River at Cundletown) are also sited adjacent to caravan parks, affording views of their structures, whilst others (Lagoon Creek at Narrabri, Peachtree Creek at Penrith and Crookwell River at Crookwell) cross flood plains or overflow channels in towns which have consequently been kept free of development, and thus affording some public access. The Stringybark Creek Bridge at Lane Cove, once a dominant arch in the landscape, has all but disappeared due to widening and regrowth of bushland, but its sweeping arches can still be viewed to advantage from beneath on a signposted bush track. A bridge now by-passed by its old highway but, along with its twin sister, known for its visual impact, is Hillas Creek Bridge at Tarcutta. So significant was its bowstring arch form that it was (and still is) referred to as "The Little Sydney Harbour Bridge".

Despite the generally modest set of bridges in the study group, it also contains some gems of public works. The Hawkesbury crossing at Richmond is a bold and noble example of bridge construction, providing a strong visual statement about its ability to both span the river and to resist the scourge of inundating floodwaters with their attacking loads of floating debris.

Hillas Creek Bridge on old Hume Highway, Tarcutta

Bridge over Berowra Creek Galston (RTA Bridge No 389)

The arch bridge at Galston is a crossing where not only the scenery is dramatic, but the elegant sweep of the open arches is visible from the twisting roadway, encouraging visitors to stop at the parking area and use the walking track to inspect the bridge from below and enjoy the power of its lines.

The king of the study in terms of visual impact is undoubtedly the Northbridge crossing. At once an arch of substantial span and height, and also carrying the heritage of its gothic styled suspension bridge past, it is impressive from every angle. The reinforced concrete elements, designed in mixed Norman and gothic styles incorporate approach arches and a main span with twin ribs and soaring piers supporting a deck with detailing embellishments to match the sandstone towers.

Northbridge southern abutment and tower (RTA Bridge No 172)

Oaky Creek Cobbadah (RTA Bridge No 3670)

Perhaps the unsung hero of the set is the barrel vaulted ribbon arch over Oakey Creek at Cobbadah, a modest rural road. The crossing appears to be no more than a culvert, with tree covered fill batters topped by an old chain wire and timber post fence, yet the structure when seen from stream level has beautiful lines as the arch widens towards its springings to support the width of the batters.

1.5.4. Visual Evidence of the Construction Process in the Fabric of the Bridges

All of the bridges in the group bear evidence of the construction processes characteristic of their period. One of the earliest bridges (Muttama Creek at Cootamundra) used corrugated iron as formwork. The fact that the earliest section of crossing at Peach Tree Creek Penrith was also constructed using corrugated iron formwork is seen as evidential of an early construction date. Later bridges used timber formwork which was eventually phased out by large sheets of formply. These developments left their imprint on the finished work.

Corrugated iron formwork

Timber formwork

Formply

Falsework used to support the formwork was originally made from timber, with concrete footing pads for this still visible under some bridges. (While this timber falsework was eventually replaced by standardised steel frames, there is no evidence of the transition). Within the concrete, the reinforcing steel had to be supported above the formwork to provide sufficient cover of concrete to prevent corrosion of the steel. This has been achieved by a variety of means over the years, with most work of the period being supported on small cubes of concrete referred to as Aspros. The marks of many of these can be seen on the undersides of bridges in the study group. Later, bar chairs were made from steel wire, then tipped with plastic, and finally made completely from plastic. These changes have reflected sometimes poor performance of these systems which, when they allowed the ingress of moisture to the steel, triggered corrosion.

Bridge over Eucumbene River (No 6049)
Freeze/thaw damage to kerb

The concrete itself in some cases bears testimony to its origins. At Tuena the rounded local quartz pebbles are visible. The bridges on the Summit Road near Charlottes Pass and Eucumbene River, Kiandra show the coarse finish of locally sourced aggregates, and all also bear the scars of 60 winters which has resulted in freeze/thaw damage to upper surfaces. On other bridges the spalling has been caused by insufficient cover to the reinforcement, reminding us that quality control has always been important, and its absence will finally betray itself. These individualities of texture, and particular material failures, are absent from the pre-stressed, trucked-in components which characterise most modest concrete bridges built since the late 1960s.

1.5.5. Relationships with Communities

The cohort of bridges comprising the study group have a diverse set of relationships with the community. Some are in Sydney, others in country towns and some on long stretches of highway joining regional centres. As evidenced by replies from local historical societies, some bridges have been created and satisfactorily performed a function while remaining almost totally unnoticed, or have been simply experienced as part of general road improvements. Others provided much relief to locals at the time of construction, (although now are generally taken for granted) alleviating the stress of being stranded (or washed away eg Yaminba Ck, Mullaley) in floods or having part of the town cut off (Cootamundra, and Riverstone), some connected to a community's sense of pride or identity (Cundletown called by The *Wingham Chronicle* of 3rd Nov 1933 'a grand sample of modern architecture'). Some were involved with local events, the most spectacular story being Northbridge, where the arch was constructed in the face of potential collapse of the suspension bridge. The most enduringly controversial has perhaps been the bridge over the Hawkesbury at Richmond where, despite being higher than its predecessor, the bridge is still subject to immersion during floods. The need to lower the railings on the bridge for such events meant that for many years the bridge had a caretaker, a role normally restricted to bridges with opening spans. Complaints, defences, demands for a yet newer and more reliable structure, have flooded the DMR and the RTA over the years in relation to this bridge.

As discussed above, in many instances local communities have not just been passive recipients of the structures but have played an active role in lobbying for (and debate over) bridge construction or improvements another example is the bridge over Yaminba Creek on the Oxley Highway where local residents as well as the Borah Creek Branch of the Agricultural Bureau had made applications to the DMR for a bridge[30].

1.5.6. Interface of the Bridge Design and Construction Process with the Community

As noted above, many communities were in the forefront of exerting pressure on government departments to improve the local infrastructure. Many roads in the first decades of the Twentieth Century were susceptible to quick degradation during rain, and stream crossings were even more vulnerable. Community action was therefore directed to achieving all-weather roads and bridges on main routes. This action usually took the form of written dialogue with the local representative of the Department of Main Roads (or its predecessors), and in some cases, via members of parliament.

Once the need for a new crossing was established, the site was surveyed, soil investigations undertaken and the catchment area measured. This work was typically undertaken by DMR personnel or contractors working for them. Bridges were typically designed by the Bridge Section in Sydney, with construction being undertaken through divisional offices. Construction was either by the Department's own work force (so-called day labour) or let out by tender to private contractors. Many local contractors were engaged. Irrespective of contractual arrangements, the majority of input was labour and the supply of materials, much of which was available locally – all assisting the local economy. This can be quite a tight loop as in the case of the Kosciusko Hotel which agitated for bridges on its access road (Summit Road) and then had the senior members of the construction team as guests during the building, and also assisted in evacuating the construction sites when bad weather hit.

Bridge building is a specialised and highly skilled trade. Several generations of bridge builders were involved in the construction of the bridges in the study group. Construction in the period under study had certain salient features that made the builders a particular kind of community in an unusual workplace. The workers were often accommodated in camps due to the on-site pouring process which, when concrete was mixed by hand, was a slow, labour-intensive activity, and one which could not be suspended at convenience but which had to reach pre-designed construction joints. The study period saw an increasing mechanisation of the road and bridge construction process with petrol driven mixers replacing hand mixing of concrete for example.

Concrete mixer 1947 – Cockle Creek railway bridge (Photo Max Broadbent)

For some of the bridges the RTA files contain quite rich detail on this early labour intensive style of construction. For the construction of the bridge over Spring Creek, Bathurst, for example, a camp for approximately twelve men was constructed on an adjacent reserve used by travelling stock. The gang moved from Coxs River and work commenced on 25th November 1946. The work was closed for the Christmas Holidays and Foreman Spence, who lived at Wagga, who arranged for his wife and family to spend part of the school holidays with him there, renting part of a cottage overlooking the work. Construction work had finished by 23 September 1947 when the Divisional Engineer asked the district telephone office at Bathurst to disconnect the telephone service at the Construction Office. The construction team were complimented by the Department's Assistant Bridge Engineer on the high quality of their work and the efficiency with which it was carried out. (RTA Bridge File 6.177;1)

Within the RTA's files is evidence that the design and construction of bridges did not proceed in-vacuo. Examples include delays to the bridges on the Wakehurst Parkway (Middle Creek No 3 and Deep Creek) because the Second World War led to a shortage of skilled manpower. Conversely, the bridges on the Heathcote Road (over Williams and Deadmans Creek) were deemed to be of military strategic importance and hence accelerated.

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[30] RTA Survey, Design & Construction File, 11/98.152;1

Middle Creek No 3 (RTA Bridge No 148) – delayed by War

Williams Creek (RTA Bridge No 499) – Brought forward by War

Entire routes were constructed in the aftermath of the Depression in order to stimulate the economy and generate employment. Unfortunately, even the Board was affected by the economic woes in the depths of the Depression and unemployment relief works which carried 2000 people in 1929 (out of a total workforce of 4000) was curtailed completely by 1931, leaving only 1000 in jobs. By 1933 the number employed by the Board was back up to 3000, and in the mid 1930s relief works aimed directly at using unemployed labour included sections of the Princes Highway including the Cockwhy Range deviation, which contains the bridge over Higgins Creek (RTA Bridge No 740).[31]

1.5.7. Significance of Bridge Set to Today's Communities

Bridges represent a substantial and an essential part of the assets of the community. Of the bridges in the current study, the majority are on routes carrying high levels of goods and services, and their disappearance would bring much of the State to a halt. The growth in vehicle weights and increases in lane and shoulder widths have meant that many bridges built of reinforced concrete in the 1905-1948 period have already been replaced. It is therefore testimony to the success and resilience of the subject bridges that they still exist. That many have been widened and/or lengthened is a reflection of their flexibility to be incorporated in upgrades. Of those which have not been changed in width, many have had their original pipe or concrete railings replaced with guardrailing which has a better safety record in redirecting impacting vehicles. The bridges with all original features intact have thus become a minority, and one that is under pressure, particularly those outside urban areas where high transit speeds and narrow bridges compromise road safety.

Endpost damage – Spring Creek (RTA Bridge No 1002) Bathurst

In fact, quite a few of the bridges in the study have been widened only as a result of fatalities. Those not widened already have, in many instances, been investigated for upgrades in the interests of safety (quite apart from any issues of alignment etc)

In summary, the current situation is a reflection of a state of dynamic equilibrium between the competing demands on the infrastructure.

On a more socially significant level, the set of bridges has a wide range of linkages with their communities. This ranges from childhood memories of rambling along creeks, picnics and bushwalks to matters of life and death including crossing bridges to escape floodwaters and the like. Each local bridge fits within its own microcosm, tying farms together, linking families to schools, transporting goods and services. Some are known as gateways to towns or, as in the case of Northbridge, give their naming to the suburb. Even the bridges themselves provide a habitat, with most bearing the musings of tenants past ranging from political exhortations to advice how far upstream

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[31] The Roadmakers A History of Main Roads in New South Wales, Department of Main Roads NSW, 1976 pp160-161

the nearest waterhole is, and providing large canvasses for unofficial public artwork. Each bridge, no matter how modest, is thus worthy of careful investigation before decisions are made which affect its future.