NEW BRIDGEWATER BRIDGE PROJECT

BURBURY CONSULTING ON BEHALF OF
THE DEPARTMENT OF STATE GROWTH

COMPARATIVE ANALYSIS

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INTRODUCTION

The Bridgewater Crossing is part of the National Land transport network and provides a link between the Midlands Highway and the Brooker Highway. The Department of State Growth is proposing to renew the bridge crossing of the River Derwent between Granton and Bridgewater. This project proposes the demolition of the bridge.

Purcell prepared this comparative analysis of the Bridgewater Bridge and convict-built causeway with input from Mott MacDonald and Austral Tasmania. The report was prepared in part to address the response to the MPIS Amendment Request from the Tasmanian Heritage Council as follows:

> 3. The amended MPIS must include a more definitive comparative analysis of the heritage significance of the Bridgewater Bridge, building on the work already completed by Purcell and Austral Tasmania, and including research and input from an appropriate engineering body with knowledge of historic bridge construction. The analysis must include reference to the relative rarity and significance of the Bridgewater Bridge as a landmark structure that provides tangible evidence of the historic crossing point and the evolution of the place.

Background

Bridgewater Bridge is a road and rail bridge that spans the Derwent River connecting the towns of Bridgewater and Granton, north of Hobart. Bridgewater Bridge is included in the Tasmanian Heritage Register (THR) as a place of State significance.[1] The THR listing For Bridgewater Bridge (THR ID 618) includes three components: the convict-built causeway (1830-1836), the 1874 and 1893 Bridgewater Bridge ruins, and the 1942-1946 Road Rail Bridge (the current Bridgewater Bridge).

The Bridgewater Causeway is a long linear earthen and stone embankment which extends in a northerly direction from the southern shore of the Derwent at Granton for a distance of some 730 m. It carries a two lane sealed road with raised earthen embankments on either side. The redundant rail line is located on its western side following its relocation in 1908. The outline of the causeway is somewhat irregular, particularly on its eastern side. It varies in width from approximately 20-30m. The height of the causeway rises at its northern end to connect with the Bridgewater Bridge.[2]

The western side of the causeway includes evidence of its past modifications and widening. At its northern end, a low sand and mudstone retaining wall has been erected using roughly squared blocks, with several courses visible above the waterline. These works were carried out in 1863 to rectify the settlement of the causeway. Connecting at the south, the stone retaining wall has been topped with a concrete retaining wall which extends some 314 m and built a top the stone courses. It would appear to be early-mid twentieth century in origin.[3]

The current Bridgewater Bridge is considered the fourth bridge constructed at this site. Lindsay Whitham (Engineer and railway historian) summarised the history of the four bridges as follows:[4]

Bridge No. 1	Road bridge, in service 1849 to 1893
Bridge No. 2	Rail bridge, 1874 to 1908 Road bridge, 1908 to 1942
Bridge No. 3	Road bridge - 1893 to January 1908 Joint road and rail bridge, January - November 1908 Rail bridge - November 1908 to 1946
Bridge No. 4	Combined road and rail bridge; - Road 1942 onwards - Rail 1946 onwards

1 Heritage Tasmania, Tasmanian Heritage Register (THR) entry, THR ID Number 618, 'Bridgewater Bridge, Midland Highway, Granton 7030'
2 Austral Tasmania, 'Draft Bridgewater Causeway and Bridge: Historic Heritage Assessment and Archaeological Zoning Plan', 27 August 2020, p 44.
3 Austral Tasmania, 'Draft Bridgewater Causeway and Bridge: Historic Heritage Assessment and Archaeological Zoning Plan', 27 August 2020, p 44.
4 L Whitham, '*The Bridges, Roads and Rails of Bridgewater*', Papers and Proceedings: Tasmanian Historical Research Association, 36, No. 2, June 1989: 82.

Allan Knight (Chief Engineer of the Tasmanian Public Works Department) designed the bridge with assistance from David Isaacs (a Victorian consultant engineer). Construction started in 1937, and after a delay due to the war and construction of the floating Hobart Bridge, opened to road traffic in 1942, and rail in 1946.[5] This bridge is based on the American vertical lift span bridges designed by Dr AJ Waddell.[6]

The bridge consists of eleven simple welded steel plate girder spans supported on composite timber and concrete piles, three all-welded steel Pratt through trusses (one of which is the lifting span) supported by piers on concrete caissons, and the abutments, which are supported on timber piles. The simple span decks are concrete and the lifting span deck is timber.[7]

The lifting span towers are supported by the approach span trusses either side. The towers support two concrete counterweights, with each counterweight supported by six 44mm diameter wire ropes on each end. The ropes pass over two grooved large diameter sheaves on top of each tower. The lifting span is raised by twin-wound rotor electric motors, backed up by a diesel engine.[8]

It is approximately 1109 ft (338 metres) in length, with a180 ft (42.9) metre opening span that lifts to provide 98 ft 6 in (approx. 30 metres) of vertical clearance under the lifting span. The bridge carries a dual laneway road with a single rail line on the upstream side and a pedestrian path on the downstream side.[9]

Bridgewater Bridge has been assessed for heritage significance on several occasions, including by O'Conner in 1977, Austral Archaeology (1997 and 2020), Purcell (with Austral Archaeology 2020) and GHD (2009), and for nomination for the bridge's inclusion in the Tasmanian Heritage Register.

In the Tasmanian Heritage Register's listing, the assessment of significance for Bridgewater Bridge includes the following statements for the 1942-1946 Road Rail bridge:

> *… The bridge is the oldest surviving lift span bridge in Australia and is Tasmania*'s *only lift span bridge* (criterion b).
>
> *… The bridge is of historic cultural heritage significance because of its association with prominent Tasmanian engineer, Sir Allan Knight* (criterion g).[10]

GHD's assessment of the significance of Bridgewater Bridge found, (in addition to the aspects in the THR's assessment), that:

> *'The weld details were the first time in Australia, and possibly more broadly, that specific design measures were researched and implemented to reduce the risk of metal fatigue in the joints'*[11] (criterion a).
>
> *'It has some rarity values as a relatively early example of an all welded bridge'* (criterion b).

GHD also analysed previous assessments of significance for the Bridge done by O'Conner (1977), Austral Archaeology (1997) and Bill Jordan.[12] The assessments undertaken by Austral and Bill Jordan were considered a more reliable determination of significance that O'Conner's, because they were consistent with current heritage practices.[13] In addition to the aspects of significance included in the THR listing, GHD reported Austral's findings that the bridges' significance in relation to its structure and construction were that:

> *… it is the largest surviving lift span structure in Australia*
>
> *'Although designed ten years after the world's first all welded steel bridge, the Bridgewater Bridge demonstrates an unusual approach to the treatment of the weld details that was, in comparison even with later bridges, ahead of its time in its attempts to*

5 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', report to Department of Infrastructure, Energy and Resources, GHD, October 2009, p 198.
6 Dr JAL Waddell is widely considered to be the 'father of the modern vertical lift bridge' as they all follow his basic design principles. Nyman, 'Dr J. A. L. Waddell's Contributions', p 9.
7 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 197; Whitham, '*The Bridges, Roads and Rails of Bridgewater*', p73
8 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 202.
9 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 202.
10 Heritage Tasmania, Tasmanian Heritage Register (THR) entry, THR ID Number 618, 'Bridgewater Bridge, Midland Highway, Granton 7030'
11 GHD, 'Tasmania's Truss Bridges Comparative Heritage Assessment', p 198.
12 GHD does not provide a reference for Bill Jordan's assessment of significance.
13 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', pp 202-203.

> *find a solution to combat problems such as fatigue and brittle fracture';*[14]

In addition GHD reported that Bill Jordan's assessment also noted (in agreement with their own assessment) that:

> *'The bridge was the first in Australia and possibly the world with specific design measures researched and implemented to reduce the risk of metal fatigue in joints'.*[15]

Ian Cooper prepared a nomination for heritage recognition by Engineers Australia for Bridgewater Bridge in which the significance of the bridge was assessed. The assessment of significance included that:

> *The current Bridgewater Bridge is the largest surviving lift span bridge in Australia and the only one of its kind in Tasmania. This bridge may well be the oldest all-welded railway truss bridge and oldest all-welded railway lift span existing in the world.*[16]

Purcell's research can confirm that it is the largest surviving lift span structure in Australia,[17] and the second largest built in Australia, (the largest being the floating bridge across the Derwent at Hobart which had an opening span of 55m compared to Bridgewater Bridge's 42.9m).[18] Purcell can also confirm it is not the oldest surviving lift span in Australia. The Ryde Bridge (Uhr's Point) across the Parramatta River in NSW was completed in 1935, seven years before the Bridgewater Bridge road lanes were completed, and eleven years before the rail lanes and lifting mechanism were completed.

Limitations

Desk-based research, and client-provided information to date, form the basis of this report, no new archival research was undertaken. The research was limited to English language sources only.

Methods

The authors conducted a non-exhaustive review of readily available, English language: bridge studies, statutory and non-statutory heritage listings, and journal articles relating to welding, fatigue, and bridges.

Definitions

Bridge Types

In the 'Historical Overview of Bridge Types in NSW', Deck, Half-Through, and Through, Bridge types are defined. These bridge types are generally fixed, although they can also be used in moveable bridges. The bridge type of relevance to this report is the 'through' type which is defined as being:

> *usually taller trusses having bracing between the tops of bridging elements such that the traffic drives through the bridge like a spatial tunnel.*[19]

Through bridges as defined above are truss bridges. Bridgewater Bridge is a Pratt truss through bridge. Many early welded bridges were plate-girder bridges, and are generally Deck, or Half-Through bridges,[20] which are defined as follows:

> ***Deck bridges*** *have the whole of their superstructures below the level of the deck, that is, the deck sits on top of the bridge.*
>
> ***Half-through bridges*** *have a cross-section that is U-shaped. The deck spans between the bottom levels of the supporting*

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14 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', pp 204-205.
15 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', pp 202-203.
16 ID Cooper. '*Bridgewater Bridge Tasmania. Nomination for Engineers Australia Engineering Heritage Recognition*'. April 2018, pp 6-9.
17 Purcell, unpublished review of surviving lift span structures in Australia, 2020
18 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 234.
19 Cardno, and McMillan, Britton and Kell Pty Ltd (MBK), '*Study of the heritage significance of pre-1930 RTA controlled metal road bridges in NSW*', report prepared for RTA, February 2001, p 63.
20 G Alencar, A de Jesus, JGS da Silva, and R Calçada, '*Fatigue cracking of welded railway bridges: a review*', *Engineering Failure Analysis*, October 2019, 104:157

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.[21]

Figure 1 A c1933 plate-girder deck bridge, Helsinki, Finland (Source: Alencar, et al, 'Fatigue cracking of welded railway bridges', p 157).

Figure 2 A 1930-1945 half through plate-girder deck bridge in Münster, Germany (Source: Alencar, et al, 'Fatigue cracking of welded railway bridges', p 157).

Pratt Truss

There are many different types of trusses, all based on the same principle, that a triangle cannot be distorted by stress. Trusses are used for bridges as the amount of material used in constructing the bridge is relatively small compared to the weight they can carry. Squire Whipple (see Vertical Lift Bridge Development, below), the first engineer to correctly analyse the stresses in a truss, published his theories in 1869.[22]

The Pratt Truss was patented in 1844 by Caleb and Thomas Pratt. The structural principle of this truss includes vertical members in compression and diagonal members in tension. The original trusses were a 'combination' structure with timber vertical members and iron rod diagonals.[23] In the late 19th Century Pratt Trusses were made from riveted, rolled steel shapes, creating a rigid and durable truss. Many leading engineers, including Dr J.A.L. Waddell (see Vertical Lift Bridge Development, below), used Pratt trusses in their lifting (and non-lifting) bridge designs.[24]

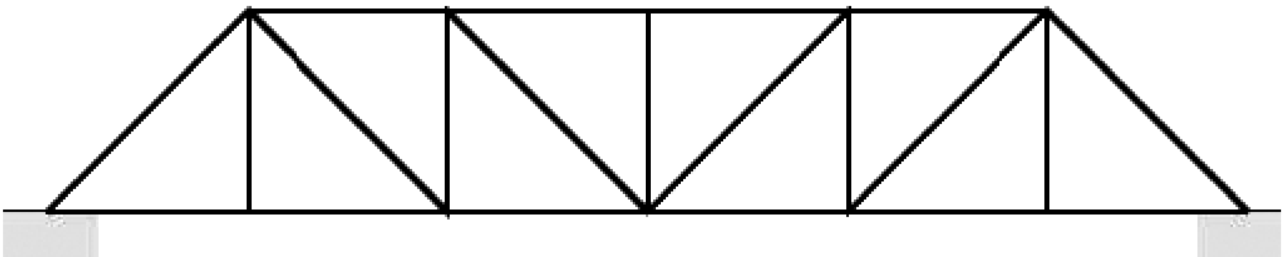

Figure 3 Diagram of a Pratt truss (Source: F Griggs Jr, Articles, Historic Structures, 'The Pratt Truss', Structure Magazine, [online], June 2016:46)

21 Cardno and MBK, '*Study of the heritage significance of pre-1930 RTA controlled metal road bridges in NSW*', p 63.
22 Britannica, The Editors of Encyclopaedia, "'*truss bridge engineering*'". Encyclopedia Britannica, 16 September 2019, accessed 3 November 2021.
23 P Brinckerhoff and Engineering and Industrial Heritage, 'A Context for Common Historic Bridge Types NCHRP Project 25-25, Task 15', prepared for the National Cooperative Highway Research Program, Transportation Research Council, National Research Council, October 2005, Chapter 2, p 7.
24 F Griggs Jr, Articles, Historic Structures, '*The Pratt Truss*', Structure Magazine, [online], June 2016:48

Vertical Lift Span Bridges

Movable bridges have many different actions including various lift span mechanisms, swing spans, and sliding spans. Bridgewater Bridge is a vertical lift span bridge. As the name suggests, the lifting span in a vertical lift span bridge rise vertically and the lifted span remains horizontal at all times.

Dr JAL Waddell is widely considered to be the 'father of the modern vertical lift bridge'. Waddell's South Halsted Street Bridge in Chicago is considered the 'first modern vertical lift span bridge'. All vertical lift bridges constructed since follow the basic design principles established by this bridge which include:

- a counterweighted span that lifts vertically while staying in a horizontal plane; and
- towers at either end of the lifting span topped by sheaves to carry the counterweight ropes

While there are minor variations in operating machinery, span and tower structural systems, and the use of chains or levers instead of ropes, all vertical lift span bridges follow these same basic design principles.[25]

25 Nyman, 'Dr J. A. L. Waddell's Contributions', p 9; GHD et al, '*Movable Span Bridge Study, Volume 1*', p 54.

COMPARATIVE ANALYSIS

THE CAUSEWAY

Various previous assessments have claimed that on completion, the Bridgewater Causeway was the largest item of convict-built infrastructure in Australia.[26] Similar statements are made in the Tasmanian Heritage Register, which notes that the causeway was the largest civil work undertaken by convict labour,[27] while the defunct Register of the National Estate cites the causeway as 'one of the largest convict built civil engineering projects undertaken in Australia'[28] and that:

> *Neither the retaining walls in Victoria Pass in the western descent from the Blue Mountains in New South Wales or the roadworks in the Great North Road, where it rises from the north bank of the Hawkesbury River have been assessed as being comparable in scale.*[29]

The veracity of this statement warrants some scrutiny, and recent work carried out by Purcell and Austral Archaeology (2020) suggests the Old Great North Road (1828-35) in New South Wales is more important as an example of civil engineering using convict labour.[30] In 2010 it was formally recognised as such with its National and World Heritage Listing as part of the eleven places that make up the Australian Convicts Serial Listing.[31]

The portion of the Old Great North Road (OGNR) included in the Serial Listing, is approximately seven and a half kilometres of the original 250 kilometre road. This includes the 5.2 kilometre Finch's Line section (built 1829-32) which is on the original line of the road and the Devine's Hill section (built 1828). The Finch's Line section ascends approximately 200 metres from the Hawkesbury River's northern bank to the plateau above. The Devine's Hill ascent incorporates massive dry stone retaining walls and extensive drainage systems. These sections involved surveying, engineering, quarrying and masonry carried out by convict gangs.[32] The quarried sandstone was "shaped, dressed and assembled to form massive retaining walls, spillways, gutters, culverts, buttresses and intricate drainage systems, most of which remain."[33] This contrasts strongly with the Bridgwater Causeway, where the quarry and Convict Station were close by and the terrain was flat. The scale of the undertaking was also much larger than at the Bridgewater Causeway, as are the remaining sections of the OGNR.

These sections of the OGNR are also substantially within their original settings and retains a high level of integrity offering a greater appreciation of the remoteness and difficulty endured by the convicts during its construction.[34] Again this contrasts strongly with the Bridgewater Causeway. Granton and Bridgewater have continued to develop so that the original setting of the causeway has been lost and the Bridgewater Causeway has been subject to change and intervention.

Nonetheless, the achievement of the Bridgewater causeway as a significant site of convict built civil engineering is a claim that has merit. However, it is perhaps difficult to establish with such certainty that it is 'the largest', and it is certainly not the largest within a national context. The category of 'civil engineering' itself is broad in scope but includes roads, bridges, canals, dams, sewerage systems, railways and so forth.

The most readily available comparisons within Tasmania are with other causeways. A cursory review would suggest they are uncommon features. Only three other causeways have been identified in Tasmania which may compare to Bridgewater: the Hunter Street causeway in Hobart; the Sorell Causeway; and the Risdon Cove Causeway.

The Hunter Street causeway connected the Hobart foreshore with Hunter Island. It was originally connected by a sand spit that was submerged at high tide. The spit was converted to a causeway between 1820-1821 by convict labour. Its length was

26 GHD, 'Bridgewater Bridge Replacement Planning Study Historic Heritage Investigations'. August 2010, p 17.
27 Heritage Tasmania, Tasmanian Heritage Register (THR) entry, THR ID Number 618, 'Bridgewater Bridge, Midland Highway, Granton 7030'.
28 Register of the National Estate (RNE), '*Bridgewater Bridge & Remains, Midland Hwy, Bridgewater, TAS, Australia*' (Place ID: 101213), accessed 27 November 2021.
29 RNE Place ID: 101213, Bridgewater Causeway, Midland Hwy, Granton, Tas, Australia
30 Purcell
31 Australian Government, Department of Agriculture, Water and the Environment (DAWE), '*Australian Convict Sites*, [website], accessed 1 November 2021.
32 Australian government, Department of agriculture, Water and the Environment, '*National Heritage Places - Old Great North Road*' [website], updated 10 October 2021.
33 Australian Government, DAWE, '*Australian Convict Sites World Heritage Nomination*', p 28.
34 Australian Government, DAWE, '*Australian Convict Sites World Heritage Nomination*', p 119.

some 182 metres. It was described as 'a substantial causeway of masonry, wide enough for two carts to pass, and a good path for foot passengers'. It has been estimated that the causeway contained more than 5,000 cubic metres of sandstone and dolerite and as much dressed sandstone on its outer sides as used in all the remaining warehouses on Hunter Street. The causeway has subsequently been consumed by later reclamation works and the formation of Hunter Street. It survives in a subsurface archaeological context.[35]

The Sorell Causeway was completed in 1874 crossing Pittwater and connecting Midway Point and Sorell. It measures some 4.8 kilometres in length. It includes a bridge crossing on its southern approach to Midway Point. It was constructed using private contractors, at a total cost of around £27,000. On construction, it included various timber-pile bridge sections, with the remainder being stone embankments and cuttings.[36]

Very little is known about the Risdon Cove causeway. It was constructed across the mouth of Risdon Cove to carry a roadway. It was in place by 1889.[37]

Beyond causeways, comparisons could perhaps be made with other civil engineering works carried out by convict labour, such as numerous extant bridges in permanent materials including Richmond (1825), Ross (1836), and the Red Bridge at Campbell Town (1836). All show skill in engineering design and fine construction using convict labour.[38]

Roads are also a type of civil engineering, the most notable being Bell's Line of Road, constructed between 1820 and 1824 by convict labour and extending for some 78 kilometres from Old Beach to St Peter's Pass.[39]

The following relevant comparisons can be made about the Bridgewater causeway:

- It is predated 10 years by the Hunter Street causeway, which also demonstrates a higher degree of detailing being clad in worked sandstone;
- At 730 metres long, 20 metres wide and containing 400,000 cubic metres of fill, the Bridgewater Causeway is substantially longer and larger in volume than the Hunter Street causeway. Its construction period of 1830-36, whilst not as early as Hunter Street, is still well within the early colonial period.
- Both Hunter Street and Bridgewater are surpassed in scale by the Sorell Causeway. However, this was constructed considerably later than the others; does not have an association with convict works; and is likely to have utilised technology that made its construction a relatively easier proposition than the older causeways.

THE BRIDGE

The current Bridgewater Bridge (the Bridge) is an all-welded, Pratt through truss, vertical lift, combined road, rail, and pedestrian bridge, designed by Allan Knight (Chief Engineer of the Tasmanian Public Works Department) with assistance from David Isaacs (a Victorian consulting engineer). Construction started in 1937, and after a delay due to the war and construction of the floating Hobart Bridge, the Bridge opened to road traffic in 1942, and rail in 1946.[40].

Welded Bridges

Arc welding was first presented at the 1881 International Electric Exposition in Paris, although it wasn't until the 1920s that 'automatic' arc welding 'machines' began to be patented.[41] Arc welding was first used to reinforce old metal railway bridges in the USA from 1926, with other countries following soon after. The main advantage was that the bridge could remain in use

35 Heritage Tasmania, THR entry, THR ID Number 10350, Hunter, Evans, Davey Street – subsurface remains including Hunter Island, Causeway, Old Wharf Probation Station and Reclaimed Land, Hunter, Davey, Evans streets, Hobart, 7000
36 The Mercury, Monday 22 June 1874, p 3
37 JB Walker, JB 'The English at the Derwent, and the Risdon Settlement', *Papers and Proceedings of the Royal Society of Tasmania*, 14 October 1889
38 Austral Tasmania, 'Draft Bridgewater Causeway and Bridge: Historic Heritage Assessment and Archaeological Zoning Plan', 2 p 53.
39 Austral Tasmania, 'Draft Bridgewater Causeway and Bridge: Historic Heritage Assessment and Archaeological Zoning Plan', 2 p 53.
40 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 198.
41 E Turyk, W Grobosz, '*Beginnings of submerged arc welding*', Bulletin of the Institute of Welding, No. 3, May-June 2014: 15-16.

while being strengthened.[42] However, this use of welding only lasted until around the end of World War Two, owing to the risk of brittle cracking and fatigue often caused by poor technique and/or poor design.[43]

Road and highway bridges were the first be constructed using welding rather than pinning or bolting. The reason being that the impact stresses were less important for a moveable load on a road than a railway bridge.[44] Poland lays claim to the first welded road bridge in the world, the first arc-welded bridge in Europe, and the first official specification for welded steel structures in the world, for their 1928 bridge over the Sludwia River near the city of Lowicz.[45]

The first all-welded railway bridges are considered to be those constructed by the Westinghouse Electric Company in the USA, c1928. One was a truss bridge at Chicopee falls, Massachusetts, and the other was a plate-girder bridge in East Pittsburgh, Pennsylvania.[46] The advantages of welding rather than riveting bridges were considered by engineers of that time to be: lighter structure weight, high efficiency, less time taken, and less clearance required, a more aesthetic finish, a more diverse range of shapes can be welded (such as cylindrical pipes), stronger tension-welded members, and a smaller workforce is required.[47] However, the technique of riveting remained the predominant method of bridge construction in the early twentieth century, mostly because of safety concerns with the new technology of welding.[48]

Bridges of Tasmania

Within the Tasmanian context, the most useful understanding of the significance of the Bridgewater Bridge comes from the 2009 GHD report,[49] which provided a comparative analysis of all of the State's metal truss road bridges.

The GHD report's comparative heritage assessment considered eight surviving metal truss road bridges in Tasmania, including the Bridgewater Bridge. The report assessed the heritage significance of each bridge and then considered the relative heritage values of each bridge when compared with others in that class of bridge. The GHD report acknowledges that the assessment method does not preclude the need to undertake standard assessment approaches to understanding the significance of a place, but rather provides a more fine-grained approach to determining the relative significance of a particular type of bridge.

The methodology used both standard assessments against heritage criteria and a qualitative approach, modifying work previously developed in Victoria for assessing historic metal road bridges. This qualitative method considered six broad criteria (age, length/height, structure type, historical issues/themes, social issues/themes, and aesthetic values), with numerical measures for each criterion. Using this system, the highest possible ranking for a bridge was a score of 18 (see Table 1).[50]

Table 1 – Summary of the eight surviving Tasmanian truss bridges

Bridge Location	Designer	Length	Construction date	Construction method	Truss type	Bridge type	Rating
North Esk River Bridge, Corra Linn	thought to be William Walker	32.7	1888	riveted cast and wrought iron	subdivided Warren	deck	12/18
George River Bridge, Priory (two spans salvaged from the South Esk River Bridge at Hadspen)	unknown	30m	1902 (relocated 1968)	rivetted steel	lattice	half-through	1/18
Kings Bridge, Launceston	WT Doyne	58m	1904	rivetted wrought iron	lattice	deck	15/18

42 G Alencar, A de Jesus, JGS da Silva, and R Calçada, 'Fatigue cracking of welded railway bridges: a review', Engineering Failure Analysis, , October 2019, 104: 155.
43 Alencar, et al, '*Fatigue cracking of welded railway bridges*', p 158.
44 Alencar, et al, '*Fatigue cracking of welded railway bridges*', p 156.
45 S Bryla, '*The first arc-welded bridge in Europe near Lowicz, Poland*', The Engineer. September 6th, 1929, p 3.
46 Alencar, et al, '*Fatigue cracking of welded railway bridges*', pp 156-157.
47 Alencar, et al, '*Fatigue cracking of welded railway bridges*', pp 155-156.
48 Alencar, et al, '*Fatigue cracking of welded railway bridges*', p 158.
49 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p .
50 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 243.

Mountain River Bridge, Lollara	A.E. Middleton	46.4m	1912	riveted steel	lattice	half-through	8/18
Nive River Bridge, Bronte (now the oldest all-welded bridge in Australia.[51])	Robert C Sharp and Allan W Knight	46m	1933	welded steel	Pratt	deck	14/18
Scamander River Bridge, Scamander (currently being demolished)	Allan Knight	118.5m	1935	welded steel	Pratt	through	9/18
Tyenna River Bridge, Westerway	Robert Charles Sharp	18m	1937	welded steel	Pratt	half-through	7/18
Bridgewater Bridge, Bridgewater	Allan Knight and DV Isaacs	42.9m lift span, 140.7m truss section, 338m total	1942-1946	welded steel	Pratt	through with lift span	14/18

For a full historical context, the report also considered demolished bridges of this type. Of these, relevant to discussion here are the Kimberley Bridge at Mersey, which was the first all-welded bridge in the State;[52] and the floating Derwent Bridge at Hobart, which was also a welded structure incorporating a similar lifting structure as used at Bridgewater (both summarised in the table below).

Table 2 – Summary of the two demolished Tasmanian truss bridges

Bridge Location	Designer	Length	Construction date	Construction method	Truss type	Bridge type
Kimberley Bridge, Mersey (washed away in the 1970 flood)	Robert Charles Sharp		1932-3	welded steel	Pratt	half through
floating Derwent Bridge, Hobart (demolished 1964)	Allan Knight and DV Isaacs	961m 54.8m clear opening	1938	welded steel (pinned sections)	Pratt	deck, with through lift span

51 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 241.
52 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 97.

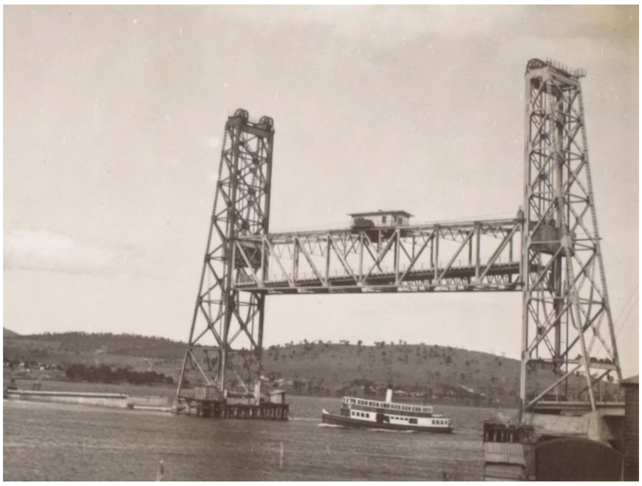

Figure 4 The floating Derwent Bridge, Hobart c1943 (Source: '[The first vessel through the lift span]', c1943, Agent-General's Office Album of Views, Libraries Tasmania)

Figure 5 Bridgewater bridge – a vertical lift, Pratt truss through bridge. (Source: '[Tugboat with barges from APPM Boyer passing under the Bridgewater Elevator bridge]', 1957, TAHO, AB713/1/5575)

As can be seen from the tables above, the closest comparison available is between the Bridgewater and Hobart Bridges as they both have all welded, steel, Pratt truss, through, vertical lift spans. The Hobart floating bridge was constructed from 1938 to 1943. It was a larger structure than the Bridgewater Bridge, having an opening span some 54 metres (180 feet) wide between its two towers, and vertical clearance of some 44 metres above the low water mark. Knight and Isaacs designed both the Hobart and Bridgewater Bridges and they were designed and constructed in close succession.[53]

Returning to GHD's comparative analysis, the report found that the Bridgewater Bridge had significance which met all criteria for entry in the Tasmanian Heritage Register. The qualitative approach gave the Bridgewater Bridge a score of 14 out of 18 total possible points, which ranked it as equal second with the Nive River Bridge in terms of its significance as a metal truss road bridge. Only Kings Bridge in Launceston received a higher score of significance.[54]

Welded Bridges in Tasmania

Electric arc welding was first introduced into Australia in 1913 by Robert Bruce and Co and E. J. Rigby, agents for the Quasi Arc Co, (an English Company). Arc welding was used to weld tracks together from 1919 by the Prahan and Malvern Tramways Trust in Victoria. By the late 1920s the Victorian Railway department were using arc welding to reinforce existing railway bridges, in a similar fashion to other countries.[55]

Arc welding began to be used in Tasmanian road bridges during the 1930s, starting with the Kimberley Bridge (1932-33 and removed), the Nive River Bridge (1933-34), the Scamander River Bridge (1934 and currently being demolished), the Hobart Bridge (1938-43), and the Bridgewater Bridge (1942-46). In each case the use of this welding technology was refined as new knowledge became available. As a technique, it was also superior to riveting, being more cost effective by being lighter and quicker to install. The initial bridges were smaller spans, with larger spans being constructed as confidence in the technology grew.[56]

The 1930s was a period of rapid development in technical knowledge. The first all welded bridge at Kimberley has since been destroyed, leaving the Nive River Bridge as Tasmania's and Australia's oldest surviving steel all welded truss bridge. The skills and knowledge developed at Kimberley and Bronte were further developed in the following bridges at Scamander, Tyenna, Hobart and Bridgewater. Collectively, they demonstrate the technical development and application of new welding technologies.[57] All of the bridges assessed in the GHD study were road bridges except for Bridgewater Bridge, being the only

53 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 239
54 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 243.
55 G Vines and K McInnes, '*Metal Road Bridges in Victoria Part 1 - History of Metal Road Bridges in Victoria*', National Trust of Victoria, Vic Roads, and Heritage Victoria, January 2003, revised August 2010, p 75.
56 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 234
57 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', pp 240-241.

composite bridge that carried road, rail, and pedestrian traffic in separate lanes.

Welded Bridges in Australia

In Victoria, VicRoads maintains a record of all metal bridges in the State. In Vines 2004 analysis of this data, there were only 12 welded steel truss road bridges out of the 3609 recorded bridges, with a further 116 Welded steel plate girder road bridges.[58]

The Sunday Creek Bridge (road deck bridge) near Seymour was constructed in 1931 by the Country Roads Board (CRB) of Victoria. The CRB described it as the first electrically welded steel truss bridge in Victoria in their Annual Reports1933-34.[59] Other welded steel truss bridges constructed in Victoria included the 1931 (rebuilt in 1934) McKillops Bridge, Snowy River (welded steel truss deck bridge) and the 1934 Grange Road Bridge, Toorak (welded steel truss deck bridge).[60]

The Sunday Creek road bridge is described by the National Trust (Victoria) as four-span, welded steel Pratt deck-truss bridge with reinforced concrete deck, piers, and abutments … and was built in a pioneering period of welded construction, contemporary with the Pikes Creek Reservoir Bridge and McKillop's Bridge over the Snowy River.'.[61] The National Trust consider it to be of aesthetic/architectural, historic, and scientific (technical) significance at a State level.[62] However, it is not included on the VHR.

None of these bridges are comparable with the Bridgewater Bridge, as all are deck, road bridges. No Victorian railway bridges were welded, as the railways were still using rivetted girders and trusses into the 1970s.[63]

NSW railways developed early and by 1925 the NSW railway system was largely complete. The majority of bridges constructed in NSW were timber owing to an abundant supply of excellent structural hardwoods in the state. [64] The other reason metal bridges were not common was the high cost of imported iron and a lack of locally produced wrought iron and steel up to about 1930. Despite steelworks being established at Lithgow in 1908 and 1916, there wasn't a sufficient supply of steel. Up until 1927 metal bridges accounted for less than three percent of the states' approximately 4,000 bridges.[65] The 1890s saw a change from use of British (wrought iron lattice truss), to American (steel truss) bridge technology, coinciding with economic quantities of structural steel imports arriving.[66] By 1922 steel Pratt truss bridges were the standard construction type, with riveted joints rather than pinned.[67] No NSW all welded bridges were discovered in the research for this study, from analysis of the lifting bridges, NSW appears to have adopted a combination of shop welding and site riveting where welding is used in bridge construction..

Vertical Lift Bridge Development

Vertical lift span bridges (as the name suggests) rise vertically and the lifted span remains horizontal at all times. Vertical lift bridges have the advantages of spanning a wide channel without obstructing a waterway; being raised 150 feet (approx. 45.7m) or higher while allowing the non-lift spans to be constructed low to the water (saving significant cost); a faster speed than swing-bridges; requiring relatively simple construction with small foundations; and having moderate power requirements. Their disadvantages include the visually imposing towers, and the tower's relative initial cost if used for short spans.[68]

Vertical lift bridges were developed in Europe and England in the 1840s. They were developed in response to the lack of

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58 G Vines, et al, 'Historic metal road bridges in Victoria', Australian Journal of Multi-disciplinary Engineering, 2004, 3(1): 78.

59 G Vines, K McInnes and G Deutsh, 'Historic metal road bridges in Victoria', Australian Journal of Multi-disciplinary Engineering, 2004, 3(1): 77; Vines and McInnes, '*Metal Road Bridges in Victoria Part 1*' p 76.

60 G Vines, et al, 'Historic metal road bridges in Victoria', Australian Journal of Multi-disciplinary Engineering, 2004, 3(1): 77; Vines and McInnes, '*Metal Road Bridges in Victoria Part 1*' p 76.

61 Heritage Victoria (HV), Victorian Heritage Database (VHD), '*Bridge over Sunday Creek*', property number B7277.

62 HV, VHD, '*Bridge over Sunday Creek*', property number B7277.

63 G Vines, '*National Trust Study of Victoria's Rail and Masonry Bridges (Masonry, Metal and Concrete Rail Bridges and Masonry Road Bridges) Part 1. Thematic History, Analysis and Recommendations*', National Trust of Australia (Victoria), 2008, revised 2010, p 105.

64 K Maxwell, '*Preservation of Historic Bridges in New South Wales*', Austroads Bridge Conference, 4th, 2000, Adelaide, South Australia, 2000,

65 Cardno, and MBK, '*Study of the heritage significance of pre-1930 RTA controlled metal road bridges in NSW*', p 63.

66 Cardno, and MBK, '*Study of the heritage significance of pre-1930 RTA controlled metal road bridges in NSW*', p 71.

67 DJ Fraser, '*Introduction of American Bridge Technology into New South Wales, Australia*', The Journal of the Society for Industrial Archeology, 21(1), 1995: 42-44.

68 WE Nyman, PE Hardesty & LLP Hanover. '*Dr. J. A. L. Waddell's Contributions to Vertical Lift Bridge Design*'. *Heavy Movable Structures, Inc. Ninth Biennial Symposium "Preserving Traditional Values with New Technologies"*. October 22 - 25, 2002 p 5.

space in certain locations, often inland canals, for the construction of swing bridges. Swing bridges required an on-shore turntable, a counterweight span on land and cantilever span over the canal. In wider canals the turntable might be located on a central pier with cantilevered spans on both sides. When swung, they either took up space for a distance along the shore, or in the canal for centrally mounted bridges.[69]

In America in the 1890s the size of ships increased due to the USA's economic growth and industrialisation. The United States federal government responded to this increasing ship size by requiring that all bridges over navigable waterways have wider navigation channels to reduce navigation obstructions.[70] While patents for vertical lift bridges existed in the United States from 1872, up until 1893 they were mainly for low lift canal bridges.[71] The first patent for a lift bridge was granted in 1872 to Squire Whipple for 'Improvement in lift draw bridges'. Whipple didn't claim invention of lifting bridges, just an improvement. This bridge, the Hotel Street Bridge in Utica, New York was a through-truss lifting road bridge over the Erie Canal. It was constructed in 1874, rebuilt in 1883 and lasted until 1921 when the canal was filled in.[72] This bridge type continued to be developed and successfully constructed in America.

Dr JAL Waddell is widely considered to be the 'father of the modern vertical lift bridge'. Waddell rose to the forefront of vertical lift bridge design after designing Chicago's South Halsted Street Bridge, considered the 'first modern vertical lift span bridge'. All vertical lift bridges constructed since follow the basic design principles established by this bridge, which is that it has a counterweighted span that lifts vertically while staying in a horizontal plane, with towers at either end of the lifting span topped by sheaves to carry the counterweight ropes. While there are minor variations in operating machinery, span and tower structural systems, and the use of chains or levers instead of ropes, they all follow this same basic design.[73]

Waddell's South Halsted Street Bridge design was the first, long-span, high, vertical lift bridge constructed. However, at least four similar bridges in Europe were designed in the mid-1800s, although none were actually built.[74] The Halsted Street Bridge opened in late 1893 and was a Pratt through-truss road, rail, and pedestrian bridge, 130 feet (approx. 39.6m) long with a clear lifting height of 155 feet (approx. 47.2m) above the river.[75] These designs continued to be built and improved in America for large span lifting bridges.

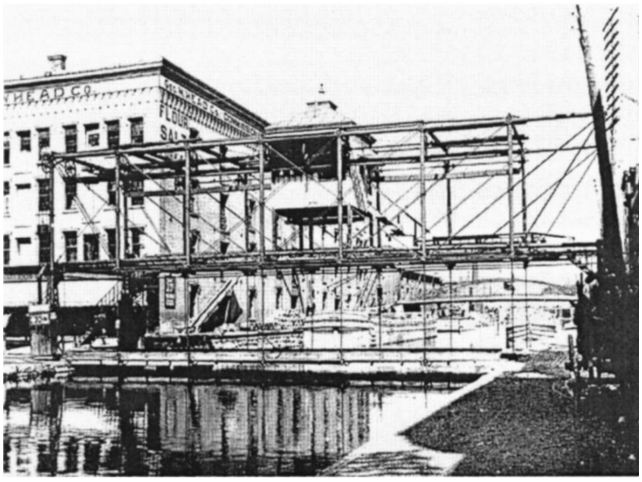

Figure 6 Hotel Street Bridge in Utica, New York (Source: Griggs, 'Development of the Vertical Lift Bridge', p 646)

Figure 7 South Halsted Street Bridge, Chicago (Source: Encyclopedia of Chicago, 'Basic Bridge Types')

In Australia, vertical lift span bridges were constructed across navigable rivers with existing shipping trade, (such as the Murrumbidgee, Murray, Darling, and Barwon Rivers) from as early as 1882 to carry road traffic. The Ryde Bridge across the

69 FE Griggs Jr, 'Development of the Vertical Lift Bridge: Squire Whipple to J. A. L. Waddell, 1872–1917', Journal of Bridge Engineering, 2006, 11(5):642
70 Nyman, 'Dr J. A. L. Waddell's Contributions', p 2.
71 Nyman, 'Dr J. A. L. Waddell's Contributions', p 11.
72 Griggs, 'Development of the Vertical Lift Bridge', pp 645-646.
73 Nyman, 'Dr J. A. L. Waddell's Contributions', p 9.
74 Nyman, 'Dr J. A. L. Waddell's Contributions', pp 2-3.
75 Nyman, 'Dr J. A. L. Waddell's Contributions', p 6; GHD, I Berger, D Healy, and M Tilley, '*Movable Span Bridge Study, Volume 1: Vertical Lift Span Bridges*', for NSW Roads and Maritime Services, March 2015, p 54.

Parramatta River, completed in 1935, was the first Waddell – type lifting bridge constructed in NSW[76] (and likely in Australia).

The following timeline is an abbreviated chronology of vertical lift bridges in Australia in relation to Waddell's designs:

INTERNATIONAL

1881

Arc welding first presented at the International Exposition of electricity, Paris.

1893

The Halstead Street Bridge over the Chicago River (Chicago, Illinois) was the first vertical lift bridge designed by Dr. J. A. L. Waddell. This bridge is considered the precedent for further large span vertical lift 'Waddell Type' bridges. The 'Waddell' type bridges are considered the influence for the second generation vertical lift bridges in NSW.

1913

The Falls City and Western Railway Bridge over the Willamette River was also designed by Waddell (and Harrington). This bridge closely corresponds to the design of the Ryde Bridge (NSW) and the Bridgewater Bridge.

AUSTRALIA

1882

The Balranald Bridge over the Murrumbidgee River at Balranald was the first vertical lift bridge built in NSW.

1935

Ryde bridge is shop welded and riveted on site.

1940-1952

Hexham bridge was designed in 1940. Construction did not commence until after WWII and it was completed in 1952

1966

Harwood Bridge, the last Waddell type bridge built in NSW

TASMANIA

1943

Hobart Bridge was completed and opened to traffic. Alan Knight is credited with the concept and overall design of the floating bridge and patented it.

1946

Bridgewater bridge lift span and railway were completed, and trains commenced crossing the bridge.

Lift Span Bridges in Tasmania

The other aspect of comparison for the Bridgewater Bridge is the inclusion of a lifting span. It was not Tasmania's largest lifting span (that honour going to the Hobart Bridge), but remains the only surviving bridge of this type in Tasmania. Bridges with moving spans are rare in Tasmania generally, the only two other examples known to the author being the bascule bridge at Constitution dock, constructed in 1935 and essentially reconstructed in 1990; and the pivoting span of the Victoria Bridge which was constructed in 1960.

Whitham considers that the Bridgewater Bridge embodies the Government's desire to stimulate the post-depression economy by supporting a new industry in the form of the Australian Newsprint Mills (ANM). ANM proposed to build a factory upstream of the Bridgewater crossing, and ship raw materials and products on the river between Boyer and Hobart. ANM required a clear opening width of 120 feet and height of 100 feet to accommodate ships of between 3000 to 5000 tons. Bascule or swing-span bridges could not accommodate ships of these sizes, so the choice of a vertical lift bridge was made.[77]

The Bridgewater Bridge is a rare example of an all-welded Pratt through truss vertical lift span bridge based on the designs of American bridge designer, Dr A.J. Waddell. Waddell's first vertical lift span bridge was constructed in Chicago in 1893. Waddell's lift span design emerged from the need for a greater span to allow wider and larger ships to pass under the bridge

76 GHD et al, '*Movable Span Bridge Study, Volume 1*', p 59.
77 Whitham, '*The Bridges, Roads and Rails of Bridgewater*', pp 72-73.

without having central piers to obstruct navigation (like swing span bridges).[78] Similar requirements led to the adoption of this style of moving bridge in Australia.

There are no comparative extant bridges in Tasmania. The only other similar vertical lift span bridge built in Tasmania was in the Hobart Floating Bridge. The vertical lift span section of the Hobart bridge was wider (at 180 feet) and was the largest opening span in Australia.[79] Allan Knight designed both bridges with DV Isaacs as the consulting engineer. George Balsille (then Director of Public Works) and Knight inspected various types of lifting bridges in NSW in 1936 to determine the most appropriate type for the Derwent River. In the same year, Knight proposed a design of a curved floating bridge with a lift span for the Hobart Bridge. Knight then went to America in 1937 to study lifting bridges prior to construction of both the Tasmanian bridges.[80] While preliminary site work for the Bridgewater Bridge began in 1937, World War Two delayed construction due to materials shortages and the transfer of workers and materials to the Hobart Bridge project.[81] Construction of the Hobart Bridge began in 1938 and in contrast to the Bridgewater Bridge, the Hobart Bridge trusses were welded in the fabricators shop and connected on site with rivets. The Bridgewater Bridge opened to traffic in March 1942, although the lifting span was not operable until 1946.[82] The Hobart Bridge was opened to traffic in December of 1943.[83]

Lift Span Bridges in Australia

NSW has more movable bridges that any other state owing to the number of navigable rivers and the use of shipping through the inland.[84] The GHD moveable bridge study has identified a total of sixty-five movable bridges in the state,[85] thirty-two of which were built prior to 1920.[86] Of the thirty-three built after 1920, there are six comparative examples of Waddell-type, Pratt through truss, vertical-lift span bridges in NSW. The first one constructed in NSW was at Ryde (in Sydney) which was completed in 1935 and was one of the bridges inspected by Balsille and Knight in 1936. The other NSW bridges were constructed at: Taree (1940); Hexham (1952); Bateman's Bay (1956); Wardell (1964); and Harwood (1966).[87] All of these lift bridges were built over navigable rivers where there was existing river trade and low riverbanks. The cost of building fixed bridges long enough to achieve the required vertical clearance to allow ships to pass under was prohibitive, hence the use of opening bridges.[88] Hexham Bridge construction was delayed by World War Two, similar to Bridgewater Bridge. While Hexham Bridge was designed in 1940, construction did not commence until after the War in 1945.[89]

78 Nyman, "Dr. J. A. L. Waddell's Contributions to Vertical Lift Bridge Design," p 5-6.
79 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 234.
80 B Cole, 'Hobart's Floating Bridge: Nomination for a Heritage Recognition Award', Engineering Heritage Tasmania. Version 2, April 2014, p 7, 11; GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 96.
81 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 197.
82 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 199.
83 Whitham, "The bridges, roads and rails of Bridgewater," p 72-73; Cole, Hobart's Floating Bridge, p 7.
84 C O'Connor, *Spanning Two Centuries Historic Bridges of Australia*, Queensland, University of Queensland Press, 1985, p 44.
85 GHD et al, '*Movable Span Bridge Study, Volume 1*', pp 14-18
86 C O'Connor, *Spanning Two Centuries Historic Bridges of Australia*, Queensland, University of Queensland Press, 1985, p 44.
87 GHD et al, '*Movable Span Bridge Study, Volume 1*', p 59
88 D Carter, and G Chirgwin. 'Vertical Lift Span Bridges in NSW An Historical Perspective'. *Austroads Bridge Conference, 4th*, 2000, Adelaide, South Australia, Issue AP-G64/00 Vol 3, 2000, p 93-94; GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 12.
89 GHD et al, '*Movable Span Bridge Study, Volume 1*', pp 205-206

Figure 8 The Ryde Bridge (Source: City of Canada Bay, 'The Ryde Bridges' [website], updated March 21, 2019)

Figure 9 Bridgewater bridge – a vertical lift, Pratt truss through bridge. (Source: 'Tugboat with barges from APPM Boyer passing under the Bridgewater Elevator bridge', 1957, TAHO, AB713/1/5575)

All of these six Waddell-type bridges were built by the Department of Main Roads, NSW. The main differences between all of the bridges lie in the number of truss spans either side of the lifting span, the truss construction method, and the construction of the bridge piers and foundations. The number of approach spans is determined by the width of the river and/or the foundation soil type either side of the river. All of the NSW bridge trusses were shop welded and the welded spans were transported to the site and rivetted together, whereas the Bridgewater Bridge truss members were fabricated, erected, and welded on site.[90]

The other main difference between the NSW bridges and Bridgewater is that they are all road bridges with a footpath / cycleway on the side. Bridgewater Bridge also carries a rail line adjacent to the centrally located road lanes, with the footpath / cycleway on the opposite side of the road lanes. The NSW bridges are all supported by reinforced concrete piers, whereas the Bridgewater Bridge has piles supported by concrete caissons. Like the Bridgewater Bridge, three of the last four bridges built in NSW are still operable (The Clyde-Bateman's Bridge was operable up until it's demolition in March 2021), as is the Bridgewater Bridge. While the Ryde bridge retains the towers and pulleys, most of the lifting mechanism was removed.

Two bridges in NSW have modifications to the standard lift span design, Wardell, and Martin. Wardell Bridge has no truss spans either side of the lifting span, instead it has reinforced concrete approach spans and the towers are supported by an extra set of concrete piers on each side of the lifting span.[91] The Martin Bridge has a plate web girder lifting section rather than a Pratt through truss. All of the lifting mechanism and the towers were removed from the Martin Bridge so it is also no longer operable.

The following table summarises the NSW lifting bridges:

Table 3 – Summary of the six surviving 'Waddell' or 'Ryde' type bridges in NSW

Bridge Location	Constructed by[92]	Length	Completion date	Construction method	Movable span truss type	Bridge type
Ryde Bridge (Uhr's Point), Parramatta River, Ryde[93]	Department of Main Roads (DMR)	34.7m opening	1935	Shop-welded, site riveted steel	Pratt	through lift span
Martin, Manning River, Taree	DMR	18.2m opening	1940	Shop-welded, site riveted steel	plate web girder	deck lift span

90 DV Isaacs, 'Design of Welded Steelwork in Bridgewater Bridge, Tasmania', Transactions of the Institution of Engineers, Australia, XX11, Dec 1941, p 285.
91 GHD et al, 'Movable Span Bridge Study, Volume 1', p 229
92 The designer of these bridges in not noted in the study.
93 GHD, 'Tasmania's Truss Bridges Comparative Heritage Assessment', p 184.

Hexham Bridge, Hunter River, Hexham	DMR	37.9m opening, 348m total	1952	Shop-welded, site riveted steel	Pratt	through lift span
Clyde Batemans, Clyde River, Batemans Bay (demolished 2021)	DMR	28.7m opening, 291m total	1956	Shop welded, site riveted steel	Pratt	through lift span
Wardell, Richmond River, south of Ballina	DMR	25.4m opening	1964	Shop welded, site riveted steel	Pratt	through lift span
Harwood, Clarence River, Harwood	DMR	37.8m opening 888m total	1966	Shop welded, site riveted steel	Pratt	through lift span

Bridgewater Bridge is important because it is the largest surviving lift span bridge in Australia.[94] Bridgewater Bridge is also considered to potentially be the '*oldest surviving all-welded railway truss bridge and oldest all-welded railway lift span*'[95] existing in the world.[96] This claim would require further research to be fully justified.

There are other steel lift span bridges in Australia, all of which are generally small, carry road traffic only, and are not of the Wardell type. Most of these are also associated with crossings that use timber girder and/or timber truss approach spans. Those lift span bridges are particularly vulnerable to demolition because of the difficulties and the costs associated with maintaining and upgrading the timber approach spans.[97]

Fatigue

Bridgewater Bridge is considered important because the design demonstrates consideration of the issue of fatigue in the design of welds and also in the detailing of strengthening plates. The performance characteristics of rivetted structures (load capacity, thermal movement and fatigue) were reasonably understood from a long service history. The long-term performance of welds was not so assured, although load capacity could be demonstrated and thermal stresses could be alleviated by movement joints. The issue of fatigue was (and still is) of concern. Fatigue relates to deterioration as a result of cyclical application of significant loads over a long period of time. This is particularly of concern in rail bridges where the design load is applied periodically over an extended period of time and, depending on design, the load can cause reversal of stress in members (ie changes from tension to compression).[98]

The use of the word 'fatigue' relating to service failures of metal equipment occurred in 1854, in a paper by Braithwaite, an English engineer. The earliest fatigue tests were published in 1837 by WAJ Albert who constructed a test machine for the metal conveyor chains in the Clausthal mines. A series of disastrous railroad accidents occurred in the period to 1887 which were attributed to fatigue failures of axles, carriage couplings and rails.[99] While these fatigue failures weren't due to welding, their investigation introduced the concepts of loads, forces, stress, strength, crack propagation and design life for riveted joints that were later applied to welded joints.[100] The first books on fatigue were published in the UK (1924), USA (1927), Europe (in several countries in 1929). Shütz considers that the 'foundations were laid' between 1920-1945 for almost all of today's knowledge of fatigue, including for welded and riveted joints of structural steels in 1931.[101]

In the first half of the twentieth century, some all-welded, or weld-strengthened railway bridges developed cracks after a few years. The world's first railway bridge reportedly had cracks in the butt welds of the lower flanges within a few days of operation. After this, US national railway companies' engineers continued to construct truss bridges using rivets for a considerable amount of time.[102] The International Association for Bridge and Structural Engineering (IABSE) held its first two

94 Cooper. '*Nomination for Engineers Australia Engineering Heritage Recognition*', p 7.
95 Cooper, '*Nomination for Engineers Australia Engineering Heritage Recognition*', p 6
96 Cooper, '*Nomination for Engineers Australia Engineering Heritage Recognition*', p 7.
97 GHD et al, '*Movable Span Bridge Study, Volume 1*', pp 14-18.
98 S Wiltshier (Mott MacDonald) Unpublished notes on the Bridgewater Bridge engineering, 2020.
99 W Schütz, 'A History of Fatigue', *Engineering Fracture Mechanics*, 1996, 54(2):264.
100 Schütz, 'A History of Fatigue', p 266.
101 Schütz, 'A History of Fatigue', p 268.
102 Alencar, et al, '*Fatigue cracking of welded railway bridges*', p 160.

conferences in Paris in 1932 and Berlin in 1936. The state-of-the-art of bridge welding technology, and the relative advantages of welding over riveting were discussed and debated at these conferences.[103] However, the reasons cracking occurred was not common knowledge among bridge engineers in the 1930s.[104]

In Tasmania, the Department of Public Works was aware of the issue of brittle fracture before commencing the design of Bridgewater Bridge. Knight completed a Master's thesis in 1935 on the 1934 construction of the Leven River Bridge. The Leven River Bridge was not a truss bridge, rather a composite steel beam and reinforced concrete deck. However, the required length of the beams meant that smaller beams were spliced together by butt welding, with the webs and flanges bevelled prior. Cover plates were used to reinforce the webs, providing 25% excess strength at the splice. In his paper, Knight wrote of more recent experiment-based information regarding the *'importance of shaping the cover plates to reduce fatigue stresses'*, and that improperly designed cover plates may even reduce, rather than strengthen a welded joint when subjected to '*alternative loads*'.[105]

Isaacs was commissioned in 1935 to provide expert advice to the Department of Public Works on the most suitable structural form to enable the use of for electric welding for the construction of Bridgewater Bridge. David Isaacs worked closely with Knight and carried out the detailed design work. Isaacs also published a paper on the distribution of stresses in fillet welds in 1936.[106] In 1937 Knight was made Chief Engineer of the Department of Public Works. Also in 1937, Knight toured the USA and Canada to investigate lift span bridge design, construction, and operation.[107] Fatigue consideration in bridge design was in its early days at the time of design of the Bridgewater Bridge.[108] In 1941 David Isaacs published an article on the design of welds used in the Bridgewater Bridge.[109]

Review of Isaacs' paper on his design approach indicates that Isaacs developed a set of 'rules' for the design (design parameters). These rules put in place limitations on stress for certain types of connection. These limitations were guided by existing codes but appear to have also relied on a certain level of reasonable judgement by Isaacs. The design also used, in Isaacs words, *"a new conception of welded truss design which seems best described by the term "force flow."* This concept sought to avoid abrupt changes in both direction of forces and stress levels at connections, by the strategic use of shaped gussets, profiled to curves, and tapered stiffening plates.[110]

This concept appears to have been a combination of art and science, whereby Isaacs visualised and drew notional lines of force through the connections. Further research would be required to determine if this concept was the fore runner of a widely adopted method of analysis. It is likely that such an approach would not have been formalised by calculation until the more recent advent of computer aided design and finite-element analysis.[111]

The idea does however achieve pleasing sculptural form in the bridge, which does set it apart in aesthetic terms. As noted by Fowler in 2011, the refurbishment works carried out Bridgewater in the early 2000s found that some of the details that were originally incorporated to reduce susceptibility to metal fatigue, are now themselves still considered susceptible to fatigue. Other measures have however been effective, and the fact that fatigue was considered and addressed is still of interest. Fairly recent analysis showed that almost all elements of the bridge still had extensive remaining fatigue life.[112] The performance of the bridge in use over 80 years also seems to indicate that the approach had merit with regard to strength and fatigue performance.

103 Alencar, et al, '*Fatigue cracking of welded railway bridges*', p 156.
104 Alencar, et al, '*Fatigue cracking of welded railway bridges*', p 159.
105 AW Knight, 'The Design and Construction of Composite Slab and Girder Bridges, with Particular Reference to the Leven Bridge at Ulverstone', Masters of Engineering Thesis, University of Tasmania, 1935, p 7, quoted in GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 198.
106 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 198.
107 Cooper, Nomination for Engineers Australia Engineering Heritage Recognition, p 7.
108 Cooper, Nomination for Engineers Australia Engineering Heritage Recognition, p 7.
109 DV Isaacs, 'Design of Welded Steelwork in Bridgewater Bridge, Tasmania', *Transactions of the Institution of Engineers, Australia*, XX11, Dec 1941, pp 279-286.
110 Isaacs, 'Design of Welded Steelwork in Bridgewater Bridge, Tasmania', p 280.
111 Isaacs, 'Design of Welded Steelwork in Bridgewater Bridge, Tasmania', p 280.
112 A Fowler, 'River Derwent, Tasmania – Bridgewater Bridges – Past and Present', 16th Engineering Heritage Australia Conference Hobart November 2011, p 7.

SUMMARY AND CONCLUSION

THE CAUSEWAY

There are claims about the causeway being one of the most significant convict built works in Australia. However, the causeway was not included in the Australian Convict Sites Serial World Heritage Listing. Instead the Great North Road was chosen as being the best surviving example and an earlier example of civil work undertaken by convict labour. The current causeway is also quite different to the original causeway, having been widened and/or raised several times in the evolution of the river crossing to cope with the significant settlement of the causeway and the increased amount of infrastructure born by the causeway.

The causeway is significant in a State context.

THE BRIDGE

Table 4 Bridgewater Bridge summary of significance claims

The following table assess the claims made about the significance of Bridgewater Bridge, that it:

Claim	Source	Confirmed / Refuted	Reason
- is the oldest surviving lift span bridge in Australia	THR[113]	✘	NSW has many older bridges of other types still extant. The 1935 Ryde bridge in NSW is the oldest surviving lift span of this type (see Table 3)
- is Tasmania's only surviving lift span bridge	THR	✓	The larger Hobart bridge was demolished (See Table 2).
- is the largest surviving lift span structure in Australia	Austral[114]	✓	The lift span is the largest surviving in Australia (See Table 3)
- is a relatively early example of an all-welded bridge	GHD[115]	✓	Completed around 18 years from the first all-welded bridges (1928).
- is Tasmania's largest truss bridge	GHD[116]	✓	See Table 1.
- was the first in Australia, (and possibly more broadly), in which specific design measures were researched and implemented to reduce the risk of metal fatigue in the joints	Robert Jordan (GHD)[117]	?	More research would be required to confirm or refute this.
- ahead of its time in its attempts to find a solution to combat problems such as fatigue and brittle fracture;	Austral.[118]	?	More research would be required to confirm or refute this.
- may be the oldest surviving all-welded railway truss bridge and railway lift span in the world	Ian D. Cooper[119]	?	More research would be required to confirm or refute this. May not be able to be confirmed or refuted owing to the extent of the claim.

113 Heritage Tasmania, Tasmanian Heritage Register (THR) entry, THR ID Number 618, 'Bridgewater Bridge, Midland Highway, Granton 7030'
114 Austral Archaeology, 'National Highway Approach to Hobart - Bridgewater Planning Study Heritage Assessment: Stage 1- Volume 2', 1997, p 10.
115 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 198.
116 GHD, 'Bridgewater Bridge Replacement Planning Study', p 27.
117 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', pp 202-205.
118 Austral Archaeology, 'National Highway Approach to Hobart', p 10.
119 Chair of Engineering Heritage Tasmania, ID Cooper. '*Bridgewater Bridge Tasmania. Nomination*,' p 6.

The 2009 GHD Comparative Assessment of Tasmania's Truss Bridges has cited the technical significance of the Bridgewater Bridge. The innovative research and design of the weld details in response to fatigue and brittle fracture is cited.[120] Important advances in welding techniques have also been cited.[121] While these advances may not necessarily be major innovations in welding technology, it is their application to bridge design that is generally considered novel. At the time it was considered novel enough to form the basis of a publication by Issacs. It is not clear if these details were used in any of the other lifting bridges constructed in Australia. The construction methods employed in the NSW vertical lift bridges (shop welded and site rivetted) is not discussed or assessed by GHD in the Vertical Lift Span Bridges section of their movable bridge study.[122]

It is likely theses details were used in the floating Derwent Bridge at Hobart, as it was designed and constructed by the same team around the same time. However, it is unlikely that this technology is widely recognised as being of importance or represents a paradigm shift in the history of bridge engineering and construction.[123] This structural engineering detail would not be apparent to the general population and would not be likely to be readily apparent to professional engineers without further explanation. The level of significance of such technology might not warrant, on its own, the retention, intact and in-situ, of the entire bridge.

This comparative analysis concludes that the Bridgewater Bridge is rare and significant to the state of Tasmania. It contributes to the landmark qualities of the Bridgewater Crossing comprising a collection of historic components which speak to the evolution of the place. The Landscape and Visual Impact Assessment forming part of the MPIS notes the scenic qualities and interest of the crossing rather than the landscape qualities of the Bridgewater Bridge itself.

120 GHD, '*Tasmania's Truss Bridges Comparative Heritage Assessment*', p 205.
121 GHD, 'Bridgewater Bridge Replacement Planning Study', pp 69-71.
122 GHD et al, '*Movable Span Bridge Study, Volume 1*'.
123 Australian Heritage Council, Guidelines for the Assessment of Places for the National Heritage List, 2009, p 39.

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