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Historic Timber Bridges in New Zealand – Restoration Works and Lessons for the Future

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ABSTRACT: The paper studies two historic bridges, the Tauranga Track and Manganuku Stream. The Tauranga Track Bridge is a rare 'harp' suspension structure and has an elegant appearance. The Manganuku Stream Bridge is a Howe truss structure and its important lessons, for the designers of future timber industrial timber structures, are discussed. The paper reports on the stresses in the historic bridge members and their significance for future maintenance works.

The paper discusses the environmental advantages of timber over reinforced concrete as a building material and explains the possibility of utilising plantation grown pinus radiata 'round timber' to replace reinforced concrete as a building material.

There is a confidence growing in New Zealand for using pinus radiata for large industrial structures. An example of these structures is briefly reported.

1 INTRODUCTION

New Zealand had a tradition, before the popularity of reinforced concrete starting around 1920, of using timber for large industrial and commercial structures.

'….in New Zealand the ready supply of timber led to the use of timber truss construction for bridges. Later it became necessary to use Australian hardwoods….Once numbered in their thousands, timber truss bridges are now becoming a rarity….', Thornton (2001).

The bridges that are the subjects of this paper are the 'Tauranga Track' and the 'Manganuku Stream'. They are located in the Waioeka Gorge, which is in the Bay of Plenty region of the North Island of New Zealand. Even though they were both constructed with Australian hardwood as road bridges, they have different structural systems. The Tauranga Track Bridge is a harp suspension structure and the Manganuku Stream Bridge is a Howe truss.

At the beginning of the 1990's, the bridges were close to collapse. Fortunately, their historic value was recognised and, during the 1990's, restoration work was carried out on them. The bridges are no longer used for vehicular traffic but have become integrated with national walkways, which enable the public to walk across and enjoy them. This paper reports on recent analyses undertaken of the likely maximum stresses occurring in the structural elements to assist the prioritising of future restoration works.

2 HISTORIC SIGNIFICANCE

The Tauranga Track Bridge has a category I ranking which is reserved for the most significant buildings and structures. Category I structures are described as 'a place of special or outstanding historical or cultural heritage significance or value'. The structural elements of the Tauranga Track Bridge are light and interestingly arranged, giving the bridge an elegant appearance. As well as aesthetic appeal, this type of structure is rare in New Zealand and this bridge is the only remaining harp suspension bridge that was originally designed for road traffic, Thornton (2001).

The Manganuku Stream Bridge is a Howe truss structure, which was very common for road and rail bridges before the 1920’s and there are a number in existence, today. Some are still being used for road and rail traffic. The Manganuku Stream Bridge has a category II ranking, which is described as a place of ‘historical or cultural heritage significance or value’.

3 RESTORATION AND MAINTENANCE

During the 1990’s restoration works were carried out on these bridges by government departments. The administrator of the bridges is the ‘Department of Conservation’. The design and technical consultants were ‘Works Consultancy’ and the construction was carried out by ‘Works Civil Construction’. However, interested members of IPENZ (Institute of Professional Engineers of NZ) made important voluntary contributions.

It was difficult work to temporarily prop the bridges during restoration. Due to a small, dedicated team of engineers and construction workers, the restoration work is of a very high order. Briefs were written for the restoration of the bridges based on the principles of the International Council on Monuments and Sites Charter, ICOMOS (1993)

At present, the ongoing maintenance of both bridges is organised by the New Zealand Department of Conservation, DOC (1998). However, money to fund these works is not plentiful and ways are being sort to make the maintenance programs as efficient as possible. We have deduced the maximum bending stresses in the structural elements, which are reported in this paper. We are hoping that, by knowing these stresses, the Department of Conservation will be better able to prioritise what parts need repairing. E.g. If there are 2 elements of equal decay, the more highly stressed one will have more need of replacement.

When observing these bridges, the most obvious form of decay is the fibre loss of the timber elements, see Figs. 5 and 6. Because the bridges are now required to support pedestrian traffic, and no longer required to support road and rail traffic, the present degree of fibre loss is, typically, not a problem. However, the strength of a piece of timber is not always evident from its external appearance. I understand that the present method, to assess the strength of the timber elements, is to measure the deflection of each element under a known load. If the deflection is excessive, then the element is weak.

Figure 1 : Tauranga Track Bridge, harp suspension structure.

4 TAURANGA TRACK BRIDGE DESCRIPTION

The 58m span Tauranga Track Bridge was built across the Waioeka Gorge in 1922 to serve a fledging farming community. It is a 'harp' suspension bridge, which is rare in New Zealand. Except for the steel suspension cables and reinforced concrete pier on the left bank, the bridge elements are Australian hardwood.

"A framed timber tower supports the bridge on each bank of the river, on the true right hand bank the tower is continuous with a framed timber pier or substructure and on the left bank the tower rests on a concrete pier. The deck is supported by transoms at six points between the piers; each transom in turn supported by a steel cable that is continuous between the anchor sets on each side of the river, running over the towers and down to the transoms. There are twelve cables altogether, six on the upstream and six on the downstream side; two timber cable stays structures at transoms two and five act to stabilise the cables.

Between the transoms, a timber deck and handrail is carried on four longitudinal timber beams or stringers. The handrail is braced both to the transoms and to cantilevered deck planks. Wind bracing cables fixed to the transoms are anchored on each bank, two upstream and two downstream.", DOC (1998), see Figs.1,2 and 3.

Figure 2 : T.T.B. true left tower

Figure 3 : T.T.B. transoms and stringers

5 MANGANUKU BRIDGE DESCRIPTION

The Manganuku Stream Bridge, built by the Public Works Department and completed in 1928, has a Howe truss spanning 24.8m across the Manganuku Stream. The carriageway is 4.7m wide, see Fig. 4. Most timber bridges constructed in New Zealand for road and rail, had a Howe truss structure.

The Howe truss structure overcomes the problems of connecting the ends of timber tension members. The cleats, at the ends of timber tension members, require considerable numbers of screw, nail or bolt fixings; and finding enough space for these fixings can be very awkward for the designer.

The advantage of the Howe truss is that the web tension members are vertical. Because they do not carry compression that causes buckling in slender elements, they can be made out of steel rods. The rods pass through holes in the top and bottom chords and their ends are threaded and are secured by nuts. Large washers are placed under the nuts to reduce bearing pressures on the timber chords, see Fig. 5.

We notice, when studying the Manganuku Stream Bridge that each element has been sized according to the load it carries. An example is the diameters of the vertical steel rods, which reduce towards the middle of the span because the loads in them get less. This avoids waste, but also adds to the visual elegance and sense of correct proportions to the observer.

Figure 4 : Manganuku Stream Bridge, Howe truss structure

The bridge designers' ability to design tension members in timber structures is also evident in the compact chord splices of the Manganuku Stream Bridge, see Fig. 6. The tension forces are transferred through bolts and round steel shear keys. The bolts, as well as transferring tension load, bind the joint together and thus hold the shear keys in place. By applying the New Zealand timber structures code, (NZS3604 1999), the total splice tension capacity is 407kN. This capacity will be suitable for a bridge deck live load of 6.1 kPa. One of the largest live loadings expected for these bridges was for cattle, with a design loading of around 4 kPa.

Figure 5 : M.S.B., top chord joint

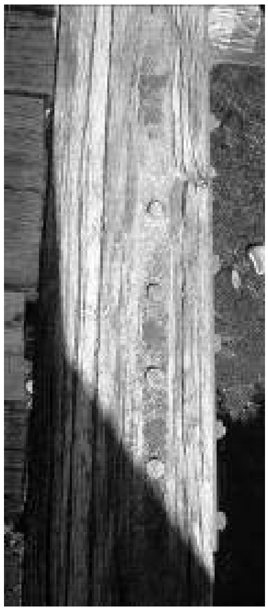


Figure 6 : M.S.B., chord splice

The truss joints have clever 'intermediate' lengths of timber, which are placed between the webs and chords, see Fig. 5. They are shaped so as to receive the squared ends of web compression members and thus relieve joint congestion and the bearing pressure normal to the timber grain. Also, they are keyed 25mm to 50mm into the top and bottom chords to assist in transferring vertical and horizontal loads into them from the webs.

6 STRESS ANALYSES

At present, the maximum loading expected on the bridge is 2KPa or 1.8kN for point loads, due to walking groups (NZS 4203). Under these conditions, the most significant bending stresses are for the transoms at 8.3 N/mm^2 and 4.3 N/mm^2 for the Tauranga Track Bridge and Manganuku Stream bridges respectively.

The axial compression stresses are relatively small for both bridges. The Tauranga Track Bridge has 8 vertical or near vertical struts at each tower. Because it is unlikely that the bridge loads will be shared equally by all 8 struts, each tower load is considered to be supported by 4 struts only. This is the basis of the calculated axial stress in the struts of 3.1N/mm^2.

The Department of Conservation can use these analyses and regard fibre loss or deterioration in the transoms as more significant than for the other timber elements. Also, a transom failure would be more catastrophic than a failure in any other type of timber member.

Table 1 : Tauranga Track Bridge, Waioeke Gorge, Opotiki, New Zealand, Stresses in Timber Members for G+Q Load Condition Q = 2.0 kN/m^2; or point load = 1.8 kN

		Decking	Stringers	Transoms	Tower Struts	Pier Piles
Depth	m	0.07	0.30	0.33	0.22	-
Width	m	1.00	0.20	0.32	0.22	-
Diameter	m	-	-	-	-	0.30
Section Area	mm^2	70000.00	60000.00	105600.00	48400.00	282743.34
Elastic Modulus, Z	mm^3	816666.67	3000000.00	5808000.00	1774666.67	21205800.00
Max Bending Action, M	kN.m	0.17	18.59	48.12	0.00	0.00
Max. Compression, N	kN	0.00	0.00	0.00	151.95	151.95
Max Shear Action, V	kN	0.92	9.29	50.65	0.00	0.00
Max bending Stress, fb	N/mm^2	3.04	6.20	8.28	0.00	0.00
Max. Compressive Stress, fc	N/mm^2	0.00	0.00	0.00	3.14	0.54
Max Shear Stress, fs	N/mm^2	0.22	0.15	0.48	0.00	0.00

Table 2 : Manganuku Stream Bridge, Waioeke Gorge, Opotiki, New Zealand, Stresses in Timber Members for G+Q Load Condition Q = 2.0 kN/m^2; or point load = 1.8 kN

		Decking	Stringers	Transoms	Chords	Webs
Depth	m	0.08	0.35	0.40	0.28	0.22
Width	m	1.00	0.16	0.30	0.39	0.26
Section Area	mm^2	75000.00	56000.00	120000.00	107250.00	57200.00
Elastic Modulus, Z	mm^3	937500.00	3266666.67	8000000.00	4915625.00	2097333.33
Max Bending Action, M	kN.m	0.26	5.99	34.22	0.00	0.00
Max. Compression, N	kN	0.00	0.00	0.00	137.00	76.30
Max Shear Action, V	kN	1.17	5.80	30.55	0.00	0.00
Max bending Stress, fb	N/mm^2	3.34	1.83	4.28	0.00	0.00
Max. Compressive Stress, fc	N/mm^2	0.00	0.00	0.00	1.28	1.33
Max Shear Stress, fs	N/mm^2	0.24	0.10	0.25	0.00	0.00

7 FUTURE INDUSTRIAL TIMBER CONSTRUCTION

7.1 Environmental reasons for timber construction

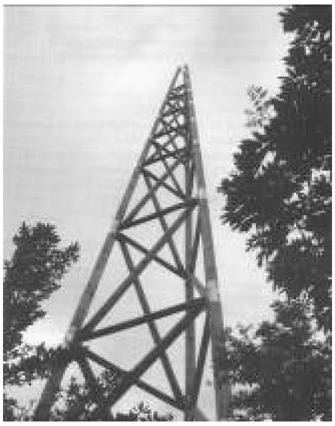
Utilising environmentally sustainable systems of building is more important each year as sources of energy become scarcer and the imbalances in the Earth's environment become more critical. There appears to be significant advantages in using timber for industrial buildings in the future. The estimated amount of the greenhouse gas, CO_2, discharged into the atmosphere for a reinforced concrete building is 95 kg/sq.m of floor area. The timber elements of an equivalent timber building will absorb and store during the trees' growth 81kg/sq.m of CO_2 from the atmosphere. Also, the energy of manufacture for a timber building @ 389Mj/sq.m is 42% that of a reinforced concrete alternative @ 932 Mj/sq.m., Chapman (2005)

7.2 Available timber species for industrial construction

Australian hardwoods are now scarce. In New Zealand, there are large areas of Pinus Radiata plantation forests, which are a sustainable source of timber. As sawn lumber, Pinus Radiata has significantly lower failure stresses than Australian hardwoods; and is considerably less durable. However, Pinus Radiata, utilised in the form of tanalith treated round timber, may be a substitute for hardwood because it has relatively high design stresses and is resistant to decay.

Round timbers, also known as logs or poles, are tree stems that have had their bark removed by peeling or shaving processes. In New Zealand and elsewhere around the world the usefulness of round timbers as elements for building structures is being recognised (Chapman 2004), see Fig. 7. Further references can be found on www.unilog.co.nz.

A commonly used Australian hardwood in historic timber bridges is Jarrah, which has design bending stresses typically around 42N/sq.mm, The design bending stresses for Pinus Radiata in the form of round timber is, also, around 42N/sq.mm, Reelick and Reelick (2004), but for sawn lumber reduces to around 17N/sq.mm. At the surfaces of sawn lumber the wood fibres are significantly interrupted at knot locations and where there is sloping grain. However, for naturally occurring tree stems, the fibres flow uninterrupted around side branches etc and sloping grain is not terminated by cuts. The lack of fibre loss leads to greater strength, Buchanan (1999). Also, round timber poles are stable and do not significantly bow or twist on drying.



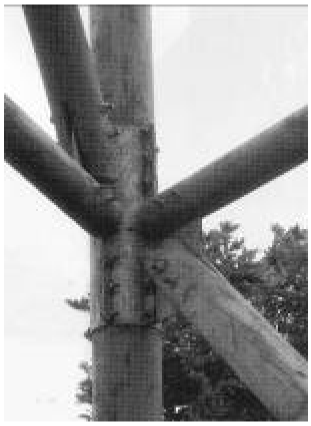


Figure 7 : Uniform round timber communications tower and joint detail

8 CONCLUSIONS

After studying these historic timber bridges, one is left in awe of their designers and constructors. The carpentry involved in preparing and fitting the heavy timber elements with no power tools is remarkable. For the Tauranga Track Bridge, the cables and associated joints required skills involved in shipbuilding as well as those of carpentry. The structural elements and their joints had to be thoroughly considered and skilfully constructed in order to transfer the very large loads they supported. The timber rail bridges supported trucks that weighed over 80 tonne.

At present, we are out of the habit of building large industrial structures in timber. However, their viability is being recognised. An example of this is the recently constructed round timber telecommunication towers whose pole elements support loads of up to 200 tonne, Reelick and Reelick (2004), see Fig. 7.

The most obvious lesson to be learnt from the Manganuku Stream Bridge is the use of the Howe truss. This structural system enables the tension members to be simple steel rods, which avoids awkward end connections for timber tension members. However, there are many other design details to inform us. One of these is the tension chord splice detail, which is explained above. Another interesting feature is the intermediate timber elements for making the joints less congested but also assist with load transference.

These historic bridge structures are elegant and contribute to their landscapes. To the observer, the arrangement and sizing of the structural elements make sense and form a harmonious and united whole. On the day that I measured the Tauranga Track Bridge, which is a 10 minute, walk away form a quiet highway; a consistent number of visitors were attracted down to view the bridge.

There are two features of the historic bridges that will not be available in future timber construction. One is the ready availability of Australian hardwoods. The other is the carpentry and shipbuilding skills for fitting the large timber elements. However, it may be possible, as discussed above, to replace the hardwood with tanalith treated Pinus Radiata round timber elements. Also, wood-working machinery that includes robotics would be able to accurately manufacture the required timber elements.

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