ASSESSING THE LOAD CARRYING CAPACITY OF TIMBER BRIDGES USING DYNAMIC METHODS

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Abstract

A reliable determination of the structural condition of timber bridges presently requires costly load testing. A new testing method is described which has recently been used to undertake field-testing of more than 20 timber bridges across NSW.

The bridge assessment procedure involves the attachment of accelerometers underneath the bridge girders. The vibration response and natural frequency of the bridge superstructure is measured when a “calibrated sledgehammer” is used to hit the unloaded deck, and then again with a relatively small mass applied at mid-span. The difference in response allows load carrying capacity of the bridge to then be calculated.

Introduction

Local Government in Australia is responsible for the operational management and maintenance of over 20,000 bridges. More than 70% of these bridges comprise aging timber bridges, the load capacity and structural adequacy of many of which have been impaired over time. A major challenge facing Local Government nationally is to develop effective strategies for the maintenance and rehabilitation of the extensive timber bridge stocks which form a key component of the road network under its control. Raising the efficiency and reliability of bridge maintenance practices of local government has the potential not only to minimise costly unscheduled emergency repairs, but also to reduce the overall maintenance costs, whilst improving the operational effectiveness of its road network.

The field testing of over 40 timber bridge spans in NSW has been undertaken and forms part of the second phase of an earlier project sponsored by IPWEA in 1999. As part of that project, a new testing regime, based on dynamic measurements, was developed and a thorough pilot study on the single span Cattai bridge in Baulkham Hills Shire was undertaken to demonstrate the potential of the proposed procedure (Ref 1).

The second phase had as its principal goal the further development and implementation of the procedure and enabling equipment for the cost-effective determination of the load deformation characteristics and load carrying capacity of a wide variety of short-span bridges. Coupled with specially developed analysis software, this provides a measure of the structural adequacy of the structure and a reliable basis for devising appropriate maintenance or remedial measures.

In consultation with some fifteen NSW councils and IPWEA, several timber bridges were chosen for implementation and further development of the procedure.

This paper presents the results obtained for one of these bridges. The bridge in question is a two span bridge from Cabonne Council which is a newly constructed timber bridge (See Figures 1 and 2). The paper presents the details of the field testing, analyses, and stiffness and load capacity results obtained for this bridge.

Figure 1 Photo of the tested bridge

Figure 2 Close-up photo of the tested bridge

Basic Concepts Underpinning the Proposed Testing Procedure

The proposed dynamic bridge assessment procedure involves the attachment of a few accelerometers underneath the bridge girders and the measurement of the vibration response of the bridge superstructure unloaded and with one or more loads (such as a truck, water tanker, grader, concrete blocks, etc, of known weight) applied at midspan. The excitation is generated by a modal impact hammer (Figure 3). The resulting dynamic responses are measured with uniaxial accelerometers which are robust and simple to attach. The data is logged and the bridge deck properties evaluated, using dynamic signal analyser or a standard computer with special software.

Figure 3 Modally Tuned ICP Sledge Hammer used for bridge tests

Two sets of bending frequencies are measured for the bridge, 'as is', and when loaded by the extra weight. By loading the bridge, the bending frequency of the bridge decreases. From the resulting frequency shift due to added weight, flexural stiffness of the bridge can be calculated.

User friendly software has also been developed which allows the estimation of bridge load carrying capacity from calculated stiffness, adopting a statistically based approach. Figure A1 of Appendix A summarises the testing and analysis procedure using the new dynamic approach. The proposed test does not require the precise measurement of deformations, as is the case for static load tests. It is also much quicker to conduct compared with load testing, and hence less expensive and much more affordable than load testing. It is also safer than load testing, particularly with respect to old bridges where applying a large load may further jeopardise the integrity of the bridge.

Brief Description of the Bridge

The two span bridge is situated on Gumble Rd, 8 km North of Orange Parks Road and is in Cabonne Council. The bridge is composed of two spans and four girders per span. The bridge is skewed at an angle of 26° to the main road.

Field Testing - Setup and Procedures

Instrumentation

Four accelerometers with high sensitivity and low frequency-range were chosen to record the accelerations of the timber bridge structure. A large 12 lb Modally Tuned ICP Sledge Hammer (Figure 3) was used to excite the bridge. Two (one eight-channel and one four-channel) Yokagawa dynamic signal analysing recorders were used to record hammer force and acceleration response signals during the tests.

A MATLAB programme was therefore developed for data processing including FFT and Frequency Response Function (FRF) calculations.

Test Setup

Four accelerometers were located at the bottom face of four girders at mid span to record the dynamic response of the girders at that point. Special base plates were also manufactured for mounting the sensors onto the bridge structure.

Testing Procedure

The field tests included two sets of tests.

Set 1 - No mass test

The bridge 'as is', without additional mass, is impacted by the modal hammer at

1) the centre of the midspan of each of the two spans.

2) top of the selected girders at the midspan of each of the two spans.

Set 2 – Added mass test

The bridge, carrying additional mass, is impacted by the modal hammer similar to no mass test.

Two types of mass distribution were used:

1) added mass is distributed uniformly at midspan of the bridge on each of the two spans, one at the time.

2) Added mass is concentrated on selected girders of the bridge on each of the two spans, one at the time

Data Processing and Analysis

From recorded dynamic response time histories and using FFT, the Frequency Response Functions can be computed. A computer programme was developed using MATLAB for this purpose. This software offers much greater flexibility when processing the test data. It produces the required Frequency Response Functions at a given bandwidth with good resolutions. The software is being further developed to incorporate more functions such as data acquisition and probabilistic models so that it can become an 'all-round' software for bridge assessment. Advanced Model Analysis software was also used in the analysis stage where highly nonlinear and coupled dynamic modes occur, for which normal methods are no longer valid.

Results

As direct results of the modal analysis, dynamic properties of the tested bridge, such as nature frequencies, damping and mode shapes, can be obtained. However, the proposed dynamic method requires only the first flexural natural frequency for both with and without added mass cases. Figures 4 and 5 show the comparison of Frequency Response Functions with and without added mass for span 1 and span 2 of the tested bridge, respectively.

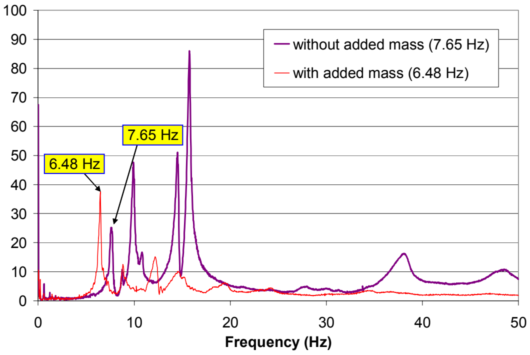

Figure 4. Comparison of sum FRFs for span 1 with and without added mass

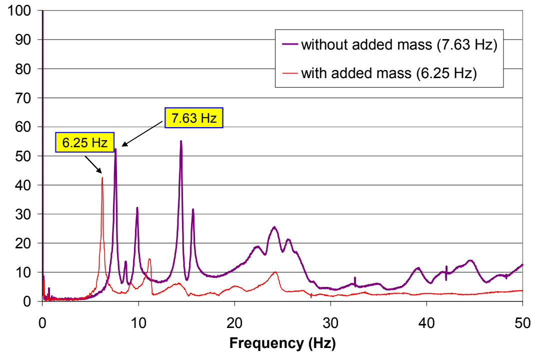

Figure 5. Comparison of sum FRFs for span 2 with and without added mass

It can be seen, clearly, that both spans possess similar natural frequencies with and without mass indicating that the two spans are in similar conditions.

Flexural Stiffness of the Tested Bridge

With added mass given, and frequencies with and without mass known, the flexural stiffness of the tested bridge can be easily calculated. Table 1 shows the amount of mass added, the first natural frequency with and without mass and prediction of the flexural stiffness of tested bridge.

Span 1	*Mass Added tonnes*	*First Natural Frequency (hz)*	*Predicted stiffness (kN/mm)*
	0	7.65	
	3.85	6.48	**20.2**
Span 2	*Mass Added tonnes*	*First nature Frequency (Hz)*	*Predicted stiffness (kN/mm)*
	0	7.63	
	3.85	6.25	**17.8**

Table 1 - Results of predicted stiffness using the proposed dynamic method

The first span stiffness is calculated as 20.2 kN/mm and the corresponding calculated stiffness for span 2 is 17.8 kN/mm. It can be seen that the stiffness results for both spans are reasonably close. This indicates that two spans are in relatively similar conditions.

Load Capacity of the Tested Bridge

The determination of strength of in-service bridge girders is extremely difficult and complex, unless of course the girder is broken and the failure load and loading pattern is known.

Current “best practice” in Australia generally assumes that the fibre strength of any girder is 80 to 100 MPa (depending upon the species). Bending capacity is predicted by multiplying the assumed section modulus "Z" (based on the gross section) by the assumed fibre strength. Whilst previous work undertaken by the RTA has involved some full scale destructive testing of girders, the basis of current load rating systems is essentially reliant upon testing of “small clear” specimens cut from these structural members, resulting in the assumption of fibre stresses noted above.

Proof loading of timber bridges is expensive and inherently risky, since it is a well established fact that high load levels cause permanent and irrecoverable damage to the wood fibres. This may result in subsequent failure of a timber girder at load levels significantly less than that indicated by the proof test. It is for this reason that most rating of timber bridges has been based on applying serviceability load levels (such as from a water tanker), measuring the deflections in order to estimate the stiffness and then using an assumed relationship between strength and stiffness to predict the load carrying capacity of each girder.

The relationship between strength and stiffness used in current load assessment methods is based on the assumed relationship between Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) defined in the Australian Timber Structures Code, AS1720.1.

However, it is not commonly understood that this relationship is both idealised and theoretical. Figure 6, illustrates the problems associated with this approach. This chart presents a plot of MOR vs MOE data obtained from full scale testing of round timbers extracted from service with an average life of 30 years and also compares this with the AS1720 relationship. It is obvious from the linear regression co-efficient for the test data that the relationship between strength and stiffness for aged poles / girders is not statistically significant. Furthermore, the theoretical relationship assumed in AS1720 is not reliable for these timbers, as many round timbers have a rupture strength significantly lower than that predicted by the Code relationship.

For example, extensive testing of some 1200 round timber pole indicates that the actual 5th percentile strengths for strength group 1 & 2 timbers range between 30 and 55 MPa, not 80 to 100 MPa as previously assumed.

In order to assess the strength of timber bridge girders with any degree of reliability, it is necessary to develop strength models, which reflect the actual bending capacity of timber. This should take into account the uncertainties associated with determination of the geometric section properties and the actual strength properties. Such a model has been developed to form the basis of the UTS load testing system developed in this IPWEA project. Using test data obtained from extensive testing of full scale round timbers, a relationship between actual measured stiffness (EI) and actual bending capacity has been derived.

Using a probabilistic approach, this relationship can be used in reliability-based models to predict the load capacity of a deck from the stiffness data obtained from the dynamic frequency method, with acceptable and transparent degrees of uncertainty.

Applying the probabilistic approach described above, the estimated live load factor (defined as the ratio of the net factored moment capacity and the moments, including live load allowance, caused by a T44 truck per lane) is 2.8 for span 1 and 2.5 for span 2. This means that the maximum load carrying capacity of the bridge is estimated at 110 tonnes.

Conclusion

A new method, based on dynamic response of timber bridges to an impact load, is proposed to measure the in-service flexural stiffness of timber bridges. Utilising a statistically based analysis, the knowledge of flexural stiffness can be converted into an estimate of the load carrying capacity of the bridge. The reliability and simplicity of the proposed methodology has been demonstrated by testing 40 bridge spans covering a wide range of single and multi-span timber bridges. The results pertaining to two spans of one of these bridges is reported in this paper, along with underlying principles and methodology adopted.

The results clearly indicate that the new dynamic procedure can provide local governments with a cost effective and reliable tool to assess the structural adequacy of their timber bridge assets. The proposed method, following the extensive testing program, has now reached a level of refinement, which can be applied to most, if not all, timber bridge types constructed in Australia. The UTS and IPWEA is pleased to offer this valuable tool to all local governments.

A point to consider is that although this methodology is capable of assessing the load carrying capacity of bridges, the load is dynamic in nature and its impact on the bridge is not just a function of the magnitude of the load. A major contributing factor is the surface condition of the bridge deck. A smooth surface will allow a much larger load to be carried safely due to low dynamic amplification attributable to smooth decks, but a similar level load may cause much distress and damage to the bridge if the surface is not sufficiently smooth. This conclusion was reached by Pesterev, et al (Ref 2) in studying the effects of dynamic loads on bridges.

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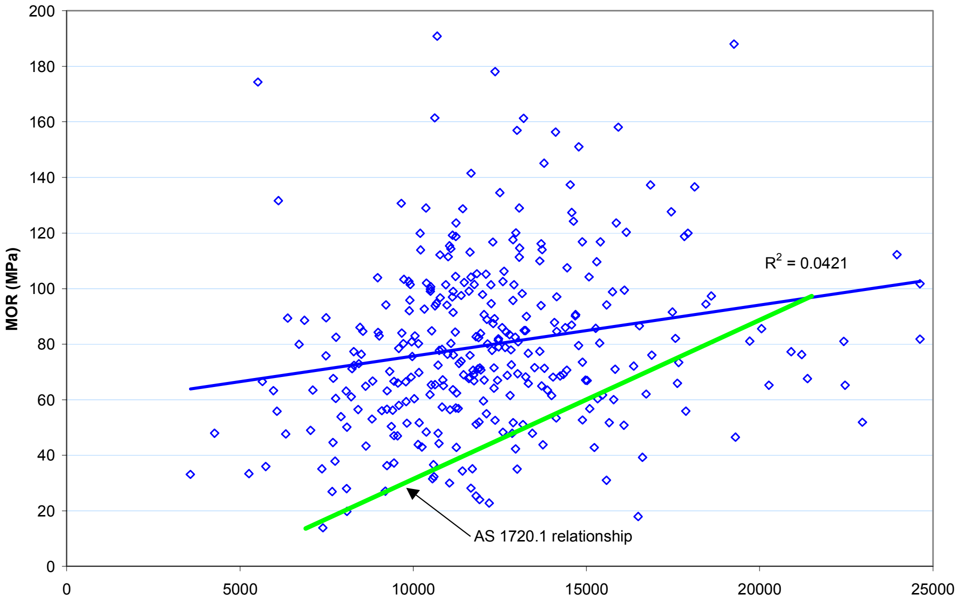
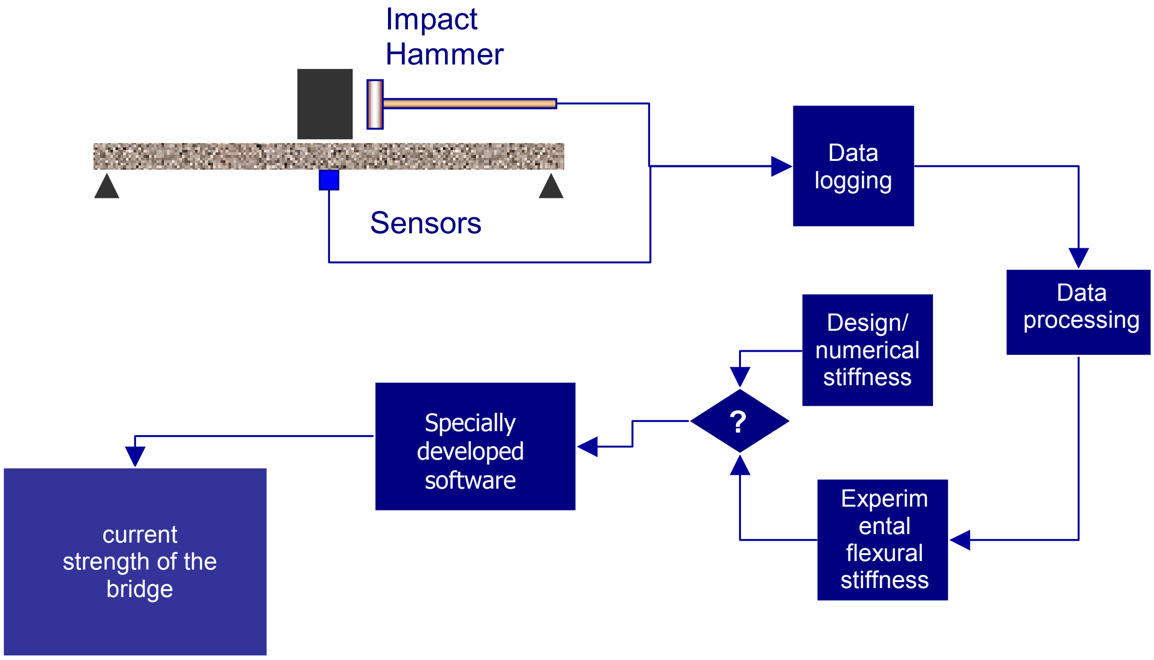


Figure 6 – MOR vs MOE for round timbers

Appendix A

Figure A1. Schematic diagram of the proposed dynamic testing/analysis procedure for bridge assessment.



Author Biographies

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Professor Bijan Samali is the current Head of Civil, Environmental and Construction Engineering at the University of Technology, Sydney and has a personal chair in Structural Engineering at UTS. He is also the Director of Centre for Built Infrastructure Research at UTS. He is currently supervising seven PhD students who are conducting research in several areas relating to Structural Control and bridge damage detection. Professor Samali has published over 150 technical papers in engineering journals and conference proceedings. His main research interests lie in the general area of structural dynamics including wind and earthquake engineering with special emphasis on structural control, dynamic measurement and analysis of buildings and bridges, and use of smart materials in engineering applications.

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Following 10 years in private practice as a Chartered Consulting Structural Engineer, Keith joined the University of Technology, Sydney in 1993, to establish an education and research program in Timber Engineering. He is currently an Associate Professor in the Faculty of Engineering and Deputy Director of the Centre for Built Infrastructure Research. His work involves teaching of various structural design subjects in both the undergraduate and graduate programs, as well as research and specialist consulting activities. Keith is the author of over 150 technical reports and papers relating to the use and reliability of structural timber and enjoys an international reputation as a Timber Engineering researcher. His consultancies include research and development and specialist design for numerous government instrumentalities, timber industry companies, developers and consultants.

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Dr Steve Bakoss is Emeritus Professor of Civil Engineering at the University of Technology, Sydney. Following eight years of practice as a structural engineer, he has had 30 years of experience of teaching structural engineering to undergraduate and postgraduate students. His recent research interests relate to new applications of Advanced Fibre Reinforced Plastics to plantation grown timbers in engineered structures, characterising recycled construction and demolition waste for use as construction materials and the assessment of the condition of major structures.

He is particularly interested in new technologies for developing and sustaining Australia's built infrastructure and has published extensively in the technical literature in related areas. Prof. Bakoss has acted as CEO of the Australian Technology Park Innovations and as consultant to State and Local Government Bodies, Public Instrumentalities, construction companies and to consulting engineers.

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Chris Champion

Chris Champion has 30 years experience in Local Government. Approximately 2 years ago he took up the position of National Chief Executive Officer of the Institute of Public Works Engineering Australia. He is also a Consultant to Local Government and the Public Works Industry. For the 12 years prior to this, he was Director of Engineering Services at Holroyd City Council in Sydney's west. Chris holds formal qualifications in Engineering, and also Local Government Management. With his interest in technology, he has also completed postgraduate qualifications in Internet Marketing. However it is "infrastructure asset management" that Chris sees as the core issue for his industry association, his profession and local government generally.

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