How to stop the rot? Continuous monitoring of short span timber bridges

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HOW TO STOP THE ROT? CONTINUOUS MONITORING OF SHORT SPAN TIMBER BEAM BRIDGES

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ABSTRACT

This paper presents the results of an investigation of a prototype system for determining the daily structural performance of timber beam bridges. Local Government authorities in New South Wales are reported to be responsible for 2500 timber bridges. The lack of appropriate resources thwarts satisfactory maintenance, thus the need to identify a low cost method of continuously measuring the health of individual spans.

Measurement of bridge girder deflection has been variously reported as an effective indicator of performance. Many existing measurement techniques apply to bridge measurement, but few can be applied to short span timber bridges with appropriate accuracy or suitable mounting method. One technique, adapted to gather typical data has been applied to a sample bridge.

Data, representative of the normal traffic flow over the sample structure, were used to develop a method of identifying structural health. The data comprised deflection measurements for a typical 24-hour period with daily reports interpreted for their temporal behaviour pattern. This monitoring technique will lead to the identification of component lifetime in the presence of degradation and enable the replacement of components prior to wear out. It will also allow for more precision in setting particular load limits for bridges while enabling a more effective prioritisation of remedial work.

Keywords: timber beam bridge, continuous monitoring, girder deflection

1 INTRODUCTION

The Roads & Transport Directorate of the Institute of Public Works Engineering Australia (IPWEA) New South Wales division reported, in 2006, the results of a survey of New South Wales (NSW) local councils and identified that for about 2500 timber bridges on local and regional roads in NSW:

- 48 % are in a satisfactory, but not good, condition;
- 30 % are in poor condition;
- The time to bring those in poor condition to a satisfactory condition is in the range 9 to 18 years at present funding levels;
- 64 % of responding councils have no knowledge of the load capacity of their bridges;
- 4 % of councils plan to load test their bridges within one year;
- 7 % of councils have staff with bridge testing accreditation skills;
- 17 % of councils have staff with bridge accreditation skills;
- 17 % of councils have qualified bridge carpenters; and
- Only 22 % of councils use contract load testing facilities.

Adapted from Roorda (2006).

Without maintenance, the 20 % of bridges that are in a satisfactory condition can deteriorate into a poor condition faster than has otherwise been expected. The reason for this is that deterioration caused by overloading or attack by termites can happen at any time and within short periods. The need to be able to continuously monitor bridge condition is urgent and currently councils do not have the maintenance capacity to do so. Because of deterioration and the lack of continuous testing there may be bridges that are at risk of failing under normally acceptable loading conditions. To reduce this risk, Roorda (2006:i) suggested the need “to improve knowledge of the condition of timber bridges and renew ageing timber bridges prior to failure”.

When a structure successfully supports a load, a reasonable expectation is that it will do so repeatedly. However, because of degradation the previous load may have damaged the structure and made it unsafe for another heavy load. An event of this type was exemplified in the case of Brodie v Singleton Shire Council where a heavy truck attempted to cross two timber bridges and the second bridge collapsed. It is unknown whether the several similarly loaded trucks that had crossed those bridges that day contributed in some way to the collapse. The court that ensued heard that the bridges were inspected about four times per year but there “was a dispute, and some uncertainty, as to the exact load-bearing capacity of the bridge in its condition at the time of the accident” (Brodie-v-Singleton Shire Council 2001:clause 25). At the time of the collapse in 2001 it was not possible to specifically identify the load-bearing capacity of any bridge at the time that it failed. In order to do so would have required instrumentation to have been installed on the bridge at that time and historically it has not been economic to do so. This current research aimed at determining instrumental methods that can be applied to the continuous measurement of bridge load-bearing capacity.

2 EXAMPLE TIMBER BEAM BRIDGES

A typical single span timber beam bridge is shown in Photo 1. It comprises three major structural components: the deck; the support girders; and the support abutments. Typically, timber bridges have spans of the order of 8-10 m, widths of 4 m and are supported by four or five girders of diameter 400-500 mm. Sometimes small spans may be used as approach sections for larger timber truss bridges as shown in Photo 2 or they may be corbelled together as in Photo 3. A typical underside is shown in Photo 4 (2008) of the Styx Bridge that was erected in 1899 (Dumaresq Shire Council 1917-1933). As can be seen in that photo the girders are major components. Significant girder failure would mean bridge failure.

Typically a timber girder can fail because of excessive loading, reduced cross-section or decreased timber strength. Excessive loads can occur because of lack of understanding of the importance of axle load and gross load. A girder can be reduced in cross-section because of weathering on the external surface or termites creating a pipe in the centre of the girder. A further loss of mechanical strength can then occur because of fungal action in a short period of time. Up to 100% loss of strength can occur in southern pine samples with a cross section of 25 mm by 10 mm in a period of 80 days (Curling *et al.* 2001). Crews (2005) identified that old timber beams could be two to three times weaker than new beams because of these types of degradations.

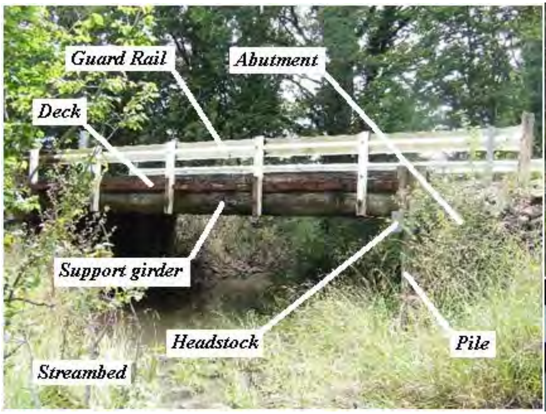

Photo 1: Example Timber Beam Bridge Powers Creek, Armidale NSW

Photo 2: Example approach span, Styx River, Armidale-Kempsey Road, NSW

Photo 3: Multiple spans corbelled together, Uralla NSW

Photo 4: Underside of Styx river bridge approach section

Measuring the mid-span deflection of the support girders has been identified by several authors as an appropriate method of identifying the structural health of timber beam bridges (Heywood *et al.* 2003; Lake 2001; Subramaniam 1994; Yttrup 2008). However, the deflection needs to be measured relatively accurately in order to determine the onset of deterioration. As is shown in Figure 1, 15% increase in deflection will occur for a 60% pipe. This would represent the onset of degradation and would be equivalent to a deflection change from 18.5 mm to 21.3 mm or an increase of nearly 3 mm. In order to determine this level of change a measurement system that has an accuracy of at least 0.5 mm is required.

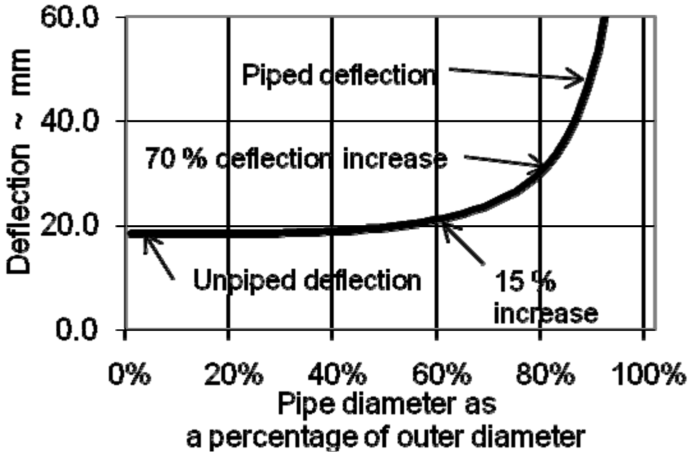

Figure 1: Effect of piping on deflection while under constant loading conditions

3 CURRENT MEASUREMENT METHODS

In the case of the bridge collapse cited above, the Court heard that the bridge was "usually inspected about four times per year" (Brodie-v-Singleton Shire Council 2001). This was unusual. Recommended visual inspection periods are typically every two years unless a structure is thought to be in a structurally poor condition when the period is reduced (QG-DMR 2002). Inspection periods of one year or more were identified as typical by Roorda (2006). It is not commercially viable to enact shorter inspection intervals when carried out manually over long periods and instrumental methods are required. Some of the methods identified as suitable for determining bridge structural integrity are:

1. Strain gauge ~ relative or requires calibration, mounting difficulties, instrumental difficulties.
2. Linear Variable Differential Transducer (LVDT) ~requires anchor.
3. Global Positioning Systems (GPS) ~ not fine enough for short spans.
4. Inclinometer ~ mounting problems on timber bridges.
5. Laser based:

a. Optical fibre interferometry ~ difficult to retrofit, instrumental difficulties, relative or needs calibration.
b. Doppler ~ difficulty of source positioning
c. Laser alignment ~ currently cited for gross movement and no reports of use on timber bridges

The methods listed are those that could be adapted to provide a continuous measurement indicative of bridge structural integrity or health. This research precluded systems that might be commonly used in engineering inspections such as drill resistance and radar. Systems that were thought to require significant development such as vibrational analysis techniques were also not considered. The system that appeared to be most suitable to be adapted to continuously record girder deflections was one based on laser technology.

4 EXPERIMENTAL METHOD

A measurement system was developed that involved mounting a laser source rigidly on one headstock next to a girder but not attached to the girder, refer **Error! Reference source not found.**. A detector was then mounted on the girder near the point of the mid-span, refer Photo 6. To protect the system from insects and weather a plastic pipe was used to span between the source and detector. The source and the detector were, prior to installation, calibrated in the laboratory. Once mounted the laser beam was manually adjusted to set the system zero. In order to reduce the amount of data the system was designed to measure the relative movement between the source and detector such that a signal was generated if the movement was above certain thresholds. Eight thresholds were used and the signal was encoded as digital binary. If the deflection was zero the output was zero. As each threshold was exceed the signal increased by one. The distance between each threshold, in millimetres, was achieved by comparing the position of the detector as measured electronically with the distance measured with a digital Vernier calliper. It was also verified that the system could adequately record peak girder deflections caused by vehicles travelling at normal highway speeds. The data were recorded by transferring to a portable memory unit. By interchanging memory units the data could be transferred to a computer and the system could continue to record data.

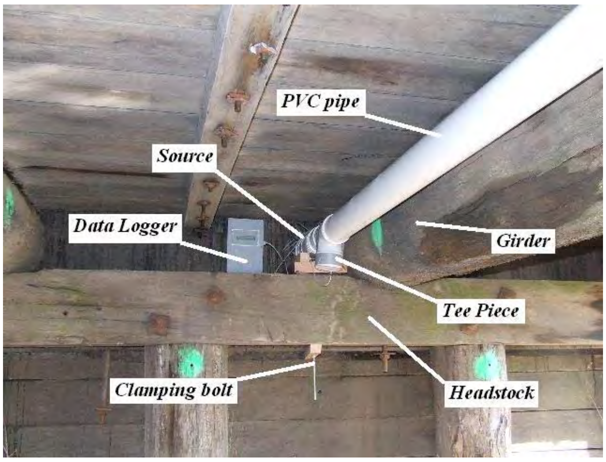

Photo 5: Source and data logger

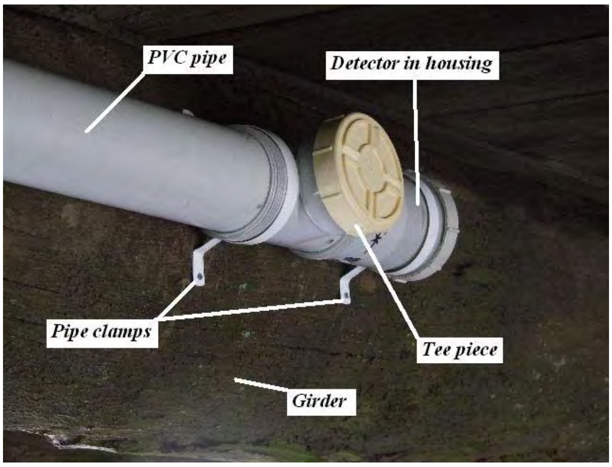

Photo 6: Detector

The system operation was checked in two ways. Firstly in order to provide a measure of calibration so that the results could be related to other bridges of different stiffness the order of magnitude of beam stiffness was measured. This was done by parking the rear axle of a truck loaded with wet sand on the bridge at mid-span and visually measuring the deflection. Secondly a known vehicle of the order of two tonne was then run over the bridge to verify that the system recorded data correctly. The system was then left for extended periods to record vehicle transits.

5 RESULTS

Table 1 provides an indication of the measurement accuracy as verified in the laboratory.

TABLE 1: Relationship between threshold design positions and measured positions

Parameter	4 m range	3 to 6 m range
Standard error of *y* estimate	0.05 mm	0.08 mm
Coefficient of determination r^2	0.999993	0.99999
Slope	0.994	
Intercept	0.7 mm	

Table 2 shows the comparison between the measured distances the laser is required to deflect for each of the eight reference thresholds and the associated mass of the vehicle causing that deflection on the timber girder.

TABLE 2: Effective thresholds on bridge

Threshold level	Measured position of thresholds in relation to reference line (mm)	Effective static loading to equal threshold with a stiffness of 0.75 tonne/mm (tonne)
1	1.92	1.4
2	4.46	3.3
3	7	5.3
4	9.54	7.2
5	19.7	14.8
6	29.86	22.4
7	40.02	30.0
8	55.26	41.4

Based upon measurements made using a loaded truck of known gross mass and relationships between gross mass and axle load, Table 2 shows the deflection for the test trailer load and the inferred girder stiffness. Photo 7 shows the five axle test truck on the small timber bridge.

TABLE 3: Estimated axle weights of test truck

Axle combination	Estimated Axle load#	Static Deflection
1 (Prime mover)	6 tonne	
2 & 3 (Prime mover)	11 tonne	
4 & 5 (Trailer)	15 tonne	20 mm
Total	32 tonne	
Girder stiffness, tonne per mm		0.75

Source: (RTA 2006)

Photo 7:Stationary truck on bridge

Figure 2 relates the 24 hour period during which continuous data were collected for this small timber bridge on the rural road outside Armidale. The deflections measured in real time were transferred from the data logger to a computer for interpretation and graphing. It is clear that the majority of vehicles caused deflections consistent with light vehicles (about one tonne) and the passage of larger vehicles, such as trucks and buses, was minimal during this period. The two peak periods were between 0700-0930 and 1530-1745 hours. During the late night-early morning, traffic was negligible.

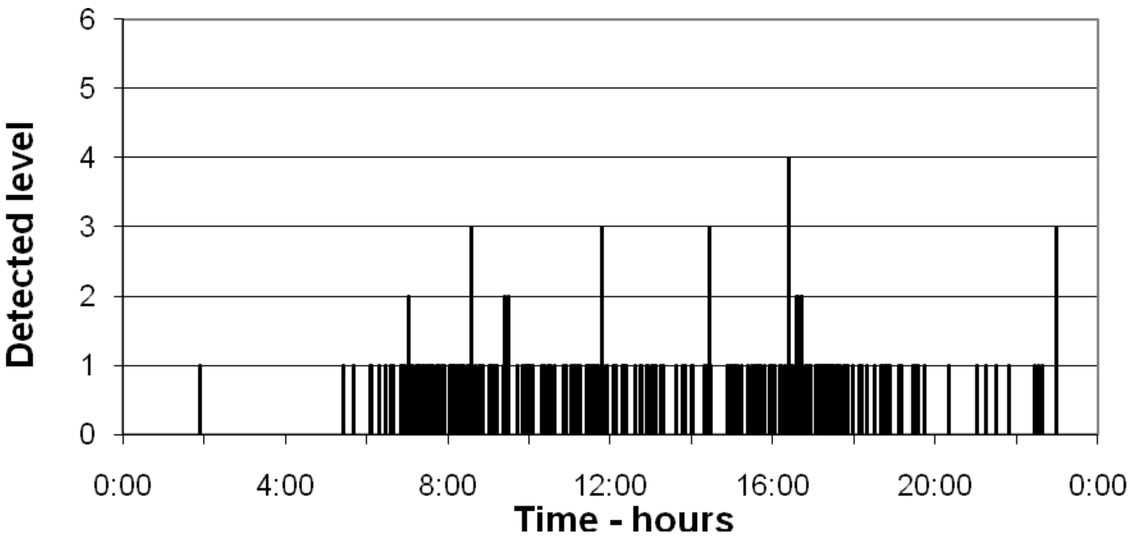

Figure 2: Graph of typical traffic over a 24 hour period

Table 4 shows the numerical relationship to Figure 2 with an assessment of the number of vehicles exceeding the threshold levels.

TABLE 4: Number of vehicles exceeding thresholds

Threshold	Number of vehicles exceeding threshold
1	300
1 but not 2	288
2 but not 3	7
3 but not 4	4
4 but not 5	1

6 DISCUSSION

The Bridge Deflection Meter was calibrated, in the laboratory, over a range of 3 to 6 metres and the results are as tabulated in Table 1. The system had a standard error of less than 0.1 mm with a coefficient of determination that was effectively unity. A small error was apparent in the slope but this related to a typical measurement error of less than 0.1 mm over the utilised measurement range of 10 mm. The system thus performed in the laboratory as well as the digital Vernier as a means to measure deflection. The design range was of the order of 0-55 mm which was a range suitable to measure both a bridge in good condition and in poor condition for the thresholds shown in Table 2. These thresholds were chosen to detect the passage of light vehicles, of about two tonnes and discriminate them from trucks in the 5-30 tonnes range. Any reduction in deflection because of vehicle speed and bridge response time has not yet been investigated in detail since the objective of this work was to identify if a viable measurement system could be created. This objective was achieved since all vehicles produced suitable deflections and enabled different weight groups to be identified.

The system was applied to a local bridge at Powers Creek south of Armidale, NSW. The source, attached as shown in **Error! Reference source not found.** was found to be very stable because of the stability of the headstock. The relative movements between source and detector were visually observed to be less than a millimetre as traffic traversed the bridge. The headstock was adequately isolated from vehicle vibration and the source did not need any isolation mountings. If required such vibration isolation would be included in the design of the measurement system and would not change the mounting system.

The two system checks produced positive results. The first test involving loading the bridge statically enabled the stiffness to be identified as 750 kg/ mm which was typical for a girder in a satisfactory to good condition, depending on the species of timber. The second test, using a vehicle of known weight, showed that the system recorded data correctly. The result of a typical 24 hour period of activity is shown in Figure 2 and Table 4. Each bar in the graph of Figure 2 represents a vehicle and the height represents the vehicle weight category. For most of the time there were no vehicles but for 180 seconds in the 24 hours the bridge was deflected. The system was considered stable since for most of the time there was no measured deflection but for the short time vehicles were present, deflections were recorded. The vehicle activity was verified by visually observing that a record occurred each time a vehicle crossed the bridge.

Of the vehicles that crossed the bridge, most were family saloon cars or small utility vehicles. These vehicles, nominally less than three tonnes, did not cause the second threshold to be exceeded. Typically only 4% of traffic on this bridge was of sufficient weight to exceed threshold two. However, this situation was only true because of the particular bridge stiffness. A lower stiffness, caused by degraded timbers, would mean that vehicles in the range 2-3 tonne would exceed threshold two. Over time, deterioration of the quality of the bridge could be detected by the number of vehicles exceeding particular thresholds, particularly ever increasing thresholds.

7 CONCLUSION

The continuous measurement of timber bridge girder deflection is readily achievable. The Bridge Deflection Meter is one such system that can be used to achieve such measurement was described. The installation and use of this meter can be used to determine the health of a bridge by enabling the bridge stiffness to be categorised. As timber girders start to degrade or ‘rot’ this often invisible process can be identified at an early enough stage to enable girders to be replaced before a bridge becomes unsafe.

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