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Approximately 4,000 vehicle bridges in the State of Minnesota contain structural timber members. Recent research at the University of Minnesota Duluth Natural Resources Research Institute (UMD NRRI) has been conducted on vibration testing of timber bridges as a means of developing rapid in-place testing techniques for assessing the structural health of bridges. The technique involves measuring the frequency characteristics of the bridge superstructure under forced flexural vibration. The peak frequency of vibration was measured and compared to a set of load testing data for each of 9 bridges. Each bridge was also inspected using commercially available advanced inspection equipment to identify any major structural problems with individual bridge components such as timber pilings, pile caps, and girders. Two bridges were identified that needed immediate maintenance attention. The relationship between the load deflection data and the vibration characteristics showed a useful relationship and the results indicate that forced-vibration methods have potential for quickly assessing timber bridge superstructure stiffness. However, improvements must be made to the measurement system to correctly identify the 1st bending mode frequency of the field bridges. This global vibration technique has potential benefits for routine inspections and long-term health monitoring of timber bridge superstructures.

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Development of Flexural Vibration Inspection Techniques to Rapidly Assess the Structural Health of Rural Bridge Systems

Final Report

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Executive Summary

Approximately 4,000 vehicle bridges in the State of Minnesota contain structural timber members. Current inspection techniques are limited to visual, sounding and coring inspections to assess the quality and performance of individual bridge members. The majority of these bridges are found in rural environments. These techniques are suitable for identifying advanced decay, but have limited effectiveness for early stage decay that causes substantial structural degrade and decreased safety if not detected. Wood is a natural occurring engineering material that is prone to deterioration caused by decay fungi and insect attack. For this reason, it is important to conduct frequent inspections of timber bridges with modern inspection equipment.

Recent collaborative research between the University of Minnesota Duluth Natural Resources Research Institute, Michigan Technological University and the USDA Forest Products Laboratory has developed vibration testing techniques for short span, simply supported timber bridges. In contrast to typical bridge inspections where individual components like pilings, girders, etc., have been evaluated, the entire bridge is tested as a system by using free and/or forced vibration. Specifically, the technique involves measuring the frequency characteristics of the bridge superstructure under free or induced flexural vibration. This research showed that both forced and free vibration could be used as rapid inspection techniques to determine the stiffness of the bridge and the corresponding overall condition.

The focus of this research project was to use forced vibration testing techniques and load testing on an additional 12+ timber bridge spans (from 9 bridges) of varying ages and designs to develop a data set for use in future commercialization and technology transfer activities. At the same time, a comprehensive inspection of each timber bridge was conducted using best practices as a means of understanding the physical health of each bridge tested. These inspections used a combination of visual inspections, physical and mechanical testing, stress wave timing techniques and resistance microdrilling techniques.

Inspection reports were completed for each individual timber bridge tested in this project. The combination of testing methods identified several bridges that required repair to the timber pilings, pile caps and girder beams. This included St. Louis County bridges 242 and 53. These repairs were made by the bridge maintenance crew from St. Louis County. The completed repairs significantly increased the service life of these bridges.

The vibration and load testing showed a useful relationship between the peak frequency of vibration and the calculated stiffness of the bridge as determined through load testing. A correlation coefficient squared (R^2) of 0.84.

The conclusions of the project were:

- The use of commercially available inspection equipment allowed the research team to identify critical areas of structural deterioration, resulting in completed repairs by St. Louis County. This deterioration typically took place in the bridge substructure, including pilings and pile caps. The use of stress wave timing and resistance microdrilling equipment allowed the inspection team to identify and quantify the decay in these bridges.
- The use of vibration testing allowed inspectors to conduct rapid inspections on bridge sections to identify a peak frequency of vibration. When compared to the bridge stiffness as

measured by load testing, a useful relationship occurred. The frequency of vibration increases with bridge stiffness.

- The vibration approach and equipment developed for this project show potential for assessing rural steel and concrete bridges, however new techniques and appropriate equipment need to be developed to adequately measure the vibration. The frequency range for the concrete bridges evaluated exceeded the available vibration capacity of the forcing motor used in this testing.

Additional studies should utilize field instrumentation that can clearly identify 1st bending mode frequencies with real time data processing tools and include automated control and data acquisition. Testing should also be conducted on dowel laminated bridge structures, which represent over 1,200 bridges in Minnesota.

Chapter 1
Introduction

The use of wood in timber bridges has many benefits including the fact that wood is a renewable and sustainable resource, that timber bridges are often more economical than steel and concrete bridges and that they can be installed easily in rural environments. There are currently over 41,000 bridges in service with a span of over 20 ft with an average age of 40 years old (FHWA 2002). This represents 7 percent of the bridges reported in the National Bridge Inventory. Recent programs like the USDA Wood In Transportation Program have funded research to develop a new class of timber bridges and associated inspection techniques. Recently the Federal Highway Administration (FHWA 2002) expanded the usage of federal "preventative maintenance" funds to include state and local bridges.

Wood is a natural occurring engineering material that is prone to deterioration caused by decay fungi and insect attack. For this reason, it is important to conduct frequent inspections of timber bridges with modern inspection equipment. As noted in the USDA Timber Bridge Manual, "Bridge members infected with decay fungi experience progressive strength loss as the fungi develop and degrade the wood structure. The degree of strength reduction depends on the area of the infection and the stage of decay development, whether advanced, intermediate, or incipient. In the advanced or intermediate stages, wood deterioration has progressed to the point where no strength remains in infected areas. At this stage, suitable detection methods can be used by the inspector to accurately define the affected areas with some degree of certainty. At the incipient or early stages of development, detection is much more difficult and the effect of strength loss varies among types of fungi." It is important to identify early stage decay to ensure the safety of the structure and allow for treatment in service.

Background discussions with Mn/DOT bridge inspection program managers and the St. Louis County bridge engineer revealed that current timber inspection procedures in Minnesota are limited to visual inspection of the wood components, sounding with a hammer and coring to confirm suspected damage areas. These techniques have proved adequate for advanced decay detection, but are not adequate when the damage is in the early stage or is located internally in the members. All inspections are completed by evaluating individual components of these bridges. This includes pilings, pile caps, girders, decking and railings. Use of advanced techniques like stress wave timing, moisture meters, resistance drills will significantly improve the reliability of the inspections but these inspection techniques are time consuming.

Deterioration, one of the most common damage mechanisms in wood structures, often inflicts damage internally, without visible signs appearing on the surface until load bearing capacity of the affected member is greatly reduced. Determining an appropriate load rating for an existing structure and establishing rational rehabilitation, repair, or replacement decisions can be achieved only after an accurate assessment of existing condition. Knowledge of the condition of the structure can reduce repair and replacement costs by minimizing labor and materials and extending service life.

In general, structural condition assessment requires the monitoring of some indicating parameters that are sensitive to the damage or deterioration mechanism in question. Current inspection methods for wood structures are limited to evaluating each structural member individually, which is a labor-intensive, time-consuming process. For field assessment of wood structures, a more efficient strategy would be to evaluate structural systems or subsystems in terms of their overall performance and serviceability. From this perspective, examining the dynamic response of a structural system might provide an alternative way to gain insight to the ongoing performance of the system. Deterioration caused by any organism or any type of physical damage to the structure reduces the strength and stiffness of the materials and thus could affect the dynamic behavior of the system. For example, if one structural system or section of the system was found to respond to dynamic loads in a manner significantly different from that observed in previous inspections, then a more extensive inspection of that structure would be warranted.

Recent cooperative research efforts of the USDA Forest Products Laboratory, Michigan Technological University, and University of Minnesota Duluth (Morison et al 2002, Morison 2003, Peterson et al 2003, Wang et al 2005) have resulted in significant progress in developing global dynamic testing techniques for nondestructively evaluating the structural integrity of wood structure systems. In particular, a forced vibration response system was developed and used to assess the global stiffness of wood floor systems in buildings (Soltis et al 2002, Ross et al 2002). In these studies, a series of laboratory-constructed wood floor systems and some in-place wood floor structures were examined. An electric motor with an eccentric rotating mass was built and attached to the floor decking to excite the structure. The response of the floor to the forced vibration was measured at the bottom of the joists using a linear variable differential transducer (LVDT). The damped natural frequencies of floor systems were identified by increasing motor speed until the first local maximum deflection response was observed. The period of vibration was then estimated from the cycles of this steady-state vibration. This forced vibration approach was investigated in these studies for two reasons. First, the simplicity of this technique requires less experimental skill to perform field vibration testing. This fits the need of field inspectors who usually do not have much advanced training in structural dynamic testing. Second, the cost of testing a structure using the forced vibration method is very low compared with the use of a modal testing method. Furthermore, because this method is a pure time domain method, it eliminates the need for knowledge of modal analysis. Results from previous experimental studies showed that vibration generated through a forcing function could enable a stronger response in wood floor systems and give consistent frequency measurement. A decrease in natural frequency seems proportionate to the amount of decay, as simulated by progressively cutting the ends of some joists in laboratory floor settings (Soltis et al 2002). It was also found that the analytical model derived from simple beam theory fits the physics of the floor structures and can be used to correlate the natural frequency (first bending mode) to *EI* product of the floor's cross section (Wang et al in press).

Cooperative research to date has provided a reasonable scientific base upon which to build an engineering application of vibration response as part of a wood structure inspection program. The purpose of this study is to extend global dynamic testing methods, specifically the forced vibration testing technique, to timber bridges in the field. It is to be used as a first pass method, identifying timber bridges that need more thorough inspection. To simplify the method as much as possible (from field application consideration), we focus only on the first bending mode of the bridge vibration. Specifically, we correlate the frequency of the first bending mode to the stiffness characteristics of single-span girder-type timber bridges.

Analytical Model

The indicator of global structure stiffness that has been chosen is the fundamental natural frequency. For practical inspection purpose, an analytic model is needed for this method to relate the fundamental natural frequency to the global stiffness properties of a bridge. Continuous system theory has been chosen as the means for developing an analytical model that is based on general physical properties of bridges, such as length, mass, and cross-sectional properties.

The superstructures of single-span timber girder bridges are typically constructed of wood beams (stringers), cross bridging, deck boards, and railing systems. It is observed that the stiffness of the stringers predominates over that of the transverse deck sheathing because the thickness of the decking boards is relatively small compared with the height of the stringers. In addition, the deck is not continuous and the deck boards are nailed perpendicular to the stringers, reducing the stiffness that would be provided in the case of simple bridge bending. The cross bridging also does not contribute to the bending stiffness of the bridge because it mainly provides lateral bracing to the beams. Thus, we assumed that a single-span wood girder bridge behaves predominately like a beam with resisting moments in the vertical direction. The total mass of the deck and railing system is distributed into the assumed mass of the stringers. The partial differential equation governing the vertical vibration for a simple flexure beam is

$$\frac{\partial^2 u}{\partial t^2} + \left(\frac{EI}{\rho A}\right)\frac{\partial^4 u}{\partial x^4} = 0$$

The solution of this partial differential equation is generally accomplished by means of the separation of variables and is largely dependent on boundary conditions at each end of the beam. (Blevins 1993) showed that a general form for the natural frequency for any mode can be derived as

$$f_i = \frac{\lambda_i^2}{2\pi L^2}\left(\frac{EI}{\rho A}\right)^{\frac{1}{2}}$$

where f_i is natural frequency (mode i), λ_i a factor dependent on the boundary conditions of the beam, L beam span, ρ mass density of the beam, A cross-sectional area of the beam, and EI stiffness (modulus of elasticity E × moment of inertia I) of the beam.

Consider the vibration of a beam supported at the ends. If vibration is restricted to the first mode, Equation (2) can be rearranged to obtain an expression for the stiffness

$$EI = \left(\frac{1}{kg}\right) f_1^2 W L^3$$

where f_1 is the fundamental natural frequency (first bending mode), k is defined as a system parameter dependent on the boundary conditions of the beam (pin–pin support: $k = 2.46$; fix–fix support, $k = 12.65$), W is weight of the beam (uniformly distributed), and g is acceleration due to gravity.

Research Objectives

The objective of this project will be conduct vibration testing of timber, steel and concrete bridges in northeastern Minnesota to determine flexural frequency characteristics. Recent collaborative research between the UMD NRRI, Michigan Technological University and the USDA Forest Products Laboratory has developed vibration testing techniques for short span, simply supported timber bridges. This research showed that both forced and free vibration could be used as rapid inspection techniques to determine the stiffness of the bridge and the corresponding overall condition.

The focus of this research proposal is to use these vibration testing techniques and load testing on an additional 9+ timber bridges of varying ages and designs to develop a data set for use in future commercialization and technology transfer activities. We plan to critically assess the testing techniques used in Michigan and adapt them for vibration testing in Minnesota. Further, we want to investigate the feasibility of the testing equipment and techniques for use on short span steel and concrete bridges.

Chapter 2

Bridges Tested

St. Louis County Bridge Number	Material Summary	Number of Spans	Year Constructed
85	Heavy timber pilings, Douglas fir girders/stringers, wood/asphalt deck	2	1946
153	Heavy timber pilings, Douglas fir girders/stringers, wood deck	1	1943
242	Heavy timber southern yellow pine pilings, Douglas fir girders/stringers, wood deck	2	1944
305	Heavy timber southern yellow pine pilings, Douglas fir girders/stringers, wood deck	2	1940
357	Heavy timber southern yellow pine pilings, Douglas fir girders/stringers, wood deck	2	1940
619	Heavy pine timber pilings, Douglas fir girders/stringers, wood deck	1	Unknown
726	Heavy timber southern yellow pine pilings, Douglas fir girders/stringers, wood deck	2	1944
CR-1	Heavy pine timber pilings, Douglas fir girders/stringers, wood deck	1	1960
CR-2	Heavy pine timber pilings, Douglas fir girders, wood deck	1	1960

Chapter 3
Procedures

Visual Inspection

The simplest method for locating deterioration is visual inspection. An inspector observes the structure for signs of actual or potential deterioration, noting areas that require further investigation. When assessing the condition of a structure, visual inspection should never be the sole method used. Visual inspection requires strong light and is useful for detecting intermediate or advanced surface decay, water damage, mechanical damage, or failed members. Visual inspection cannot detect early stage decay, when remedial treatment is most effective. During an inspection the following signs of deterioration were investigated:

- Fruiting bodies
- Sunken faces and localized collapse
- Staining or discoloration
- Insect activity
- Plant and moss growth
- Missing members
- Checks and splits
- Alterations
- Loose or missing connections

Moisture Content Determination

At the time of bridge testing, the moisture content of wood in each bridge was measured with an electrical-resistance-type moisture meter and 3-in. (76-mm) long insulated probe pins in accordance with ASTM D 4444 (ASTM 2000). Moisture content data were collected at pin penetrations of 2 in. (51 mm) from the underside (tension face) of three different timber beam girders at each bridge. All field data were corrected for temperature adjustments in accordance with (Pfaff and Garrahan 1984).

Stress Wave Timing

An example of the stress wave concept for detecting decay within a rectangular wood member is shown in Figure 1. First, a stress wave is induced by striking the specimen with an impact device that is instrumented with an accelerometer that emits a start signal to a timer. A second accelerometer, which is held in contact with the other side of the specimen, serves to the leading edge of the propagating stress wave and sends a stop signal to the timer. The elapsed time for the stress wave to propagate between the accelerometers is displayed on the timer. All commercially available timing units, if calibrated and operated according to the manufacturer's recommendations, yield comparable results. The use of stress wave velocity to detect wood decay in timber bridges and other structures is limited only by access to the structural members under consideration. It is especially useful on thick timbers 89 mm (3.5 in.) where hammer sounding is not effective. A detailed explanation of the use of stress wave timing and interpretation of the testing is detailed in publications prepared by Brashaw et al (2005).

A Fakopp Microsecond Timer was used to determine the stress wave time across the piling 6 inches above the water line, at 6 inches below the pile top and at a point midway between these two measurements. The Fakopp was also used to test the pile caps at several locations, starting on one end continuing along its length at locations between the stringers. It was also used to test the girders 12 inches away from the end above the abutment.

The Fakopp is very accurate at determining the presence of decay at the testing location and is useful in mapping the decay locations. Table 3.1 shows the stress wave transmission times perpendicular to the grain for several species at various degradation levels for the species present in the timber bridges.

Table 3.1. Stress wave transmission times perpendicular to the grain with various levels of degradation using the Fakopp Microsecond Timer.

	Stress Wave Transmission Times (microseconds/ft)			
Species	Sound Wood	Moderate Decay	Severe Decay	Splits
Douglas fir	130-260	300-400	500+	300-700
Southern yellow pine	220-250	300-400	500+	300-700

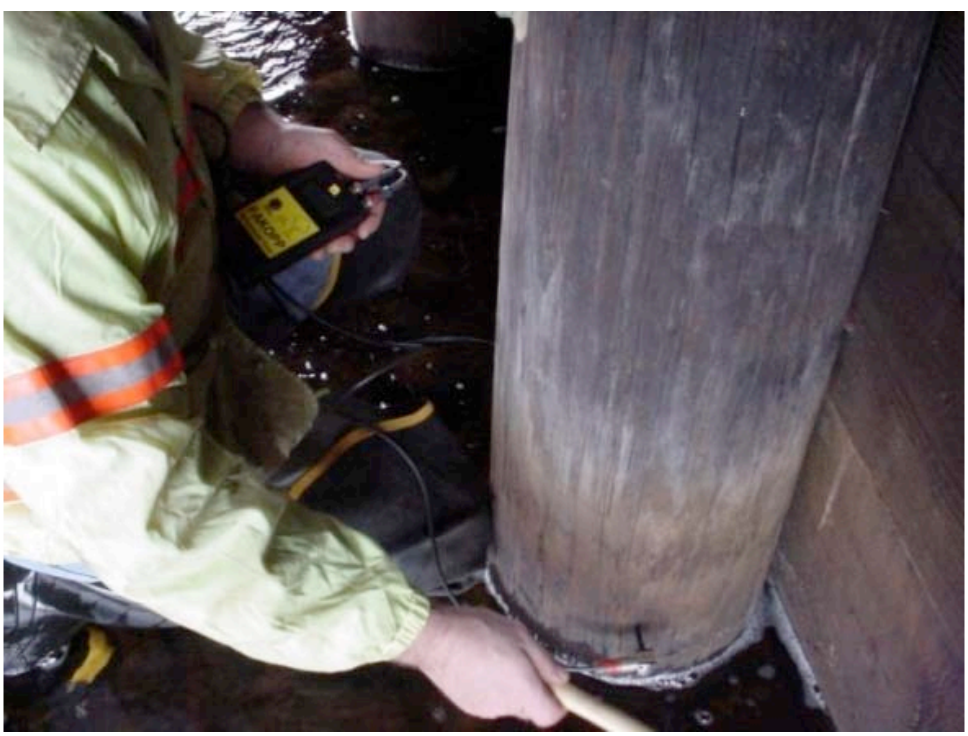

Figure 3.1. Fakopp microsecond timer being used on a timber pile.

Resistance Microdrilling

Resistance microdrilling was used to identify and quantify decay, voids, and insect galleries in wood beams, columns, poles, and piles. The resistance drill system measures the resistance of wood members to a 1.5-mm drill bit with a 3.0-mm head that passes through them. The drill bit is fed at a fixed movement rate allowing the inspector to determine the exact location and extent of the damaged area. This system produces a chart showing the relative resistance over its travel path. This chart can be produced either as a direct printout or can be downloaded to a computer. Areas of sound wood have varying levels of resistance depending on the density of the species and voids show no resistance. The inspector can determine areas of low, mild, and high levels of decay. A detailed explanation of the use of resistance microdrilling and interpretation of the testing is detailed in publications prepared by Brashaw et al (2005).

In areas of concern noted during visual and stress wave inspections, the IML F-300 resistance drill was used to test the cross-section and determine the resistance of the wood to a small diameter drill bit. An example of the Fakopp testing is shown in Figure 3.1 and the resistance drilling testing in Figure 3.2.

The resistance drilling unit was very accurate at determining the presence of decay at the drilling location. It measures the resistance on a 0-100% amplitude scale. Typical measures of resistance for sound softwoods are > 25%, 10-20% for moderate decay and 0-10% for advanced or severe decay.

Figure 3.2. Example of resistance drill testing.

Vibration Test Procedures for Timber Bridges

A forced vibration technique was used to identify the first bending mode frequency of the bridge structures. This method is a purely time domain method and was used because it eliminates the need for modal analysis. An electric motor with a rotating unbalanced wheel was used to excite the structure, which creates a rotating force vector proportional to the square of the speed of the motor. Placing the motor at midspan ensured that the simple bending mode of structure vibration was excited. Three piezoelectric accelerometers (PCB 626BO2), also at midspan, were used to record the response in the time domain. To locate the first bending mode frequency, the motor speed was slowly increased from rest until the first local maximum response acceleration was located. The period of vibration was then estimated from 10 cycles of this steady-state motion as captured using a Fluke digital scopemeter. The specific testing steps included:

1. Secure a dc motor (1/2 horsepower) with rotating unbalanced wheel to the deck plank at the center of the bridge span and anchor using steel bolt screws.
2. Secure two magnetic metal plates to deck plank, one on each side of the bridge at midspan using steel bolt screws.
3. Attach one piezoelectric accelerometer to each magnetic metal plate to monitor the bridge vibration signals.
4. Start up motor. Slowly increase motor speed to put the bridge into low frequency transverse vibration.
5. Find the first bending mode frequency by locating the first local maximum response acceleration using a digital scopemeter.
6. Record the data and start a second test.

Once all of the tests have been completed, the data is reviewed briefly and photographs are taken before leaving the test site. The typical test setup can be seen in Figure 3.3.

Figure 3.3. General test setup for vibration testing.

Static Load Testing

Because the primary goal of this work is to relate the vibrational characteristics of these timber bridge structures to a measure of structural integrity, the bridges were also evaluated with the established method of load deflection analysis. This provided a more direct measure of the structure's *EI* product. Static load tests were conducted at each field bridge using a live load testing method. A test vehicle was placed on each bridge deck and the resulting deflections were measured from calibrated rulers suspended from each timber girder along the midspan cross section using an optical surveying level. The test vehicle consisted of a fully loaded, tri-axle gravel truck. The gross vehicle weight and individual axle weights were measured for each truck used prior to testing. The axle spacing was also measured for each truck. Deflection readings were recorded prior to testing (unloaded), after placement of the test truck for each load case (loaded), and at the conclusion of testing (unloaded). For each load test, the test vehicle was straddling the bridge centerline with the bridge midspan bisecting the real dual truck axles. Measurement precision was ±0.04 in. (±1.0 mm) with no movements detected at the bridge supports. The static *EI* product of each bridge was then estimated from load deflection data based upon conventional beam theory. The specific static load test steps include:

<u>Initial Assessment of Bridge Condition</u>

1. Look for any signs of major distress in any of the support girders and load carrying beams.
2. Inspect top and bottom of road using visual and (hammer) sounding methods.
3. Look closely at abutments and pier supports to ensure that cap beams should be resting squarely on piles).
4. Do not conduct bridge test if safety is concern -- Use traffic control as appropriate!

<u>Placement of Optical Surveying Level</u>

1. Look for a suitable location on solid ground, not on soft soils or muck.
2. Ensure that the technician has a good view of all centerspan rulers, including the closest and farthest sight distances.
3. The height of instrument should be as high as possible, but not higher than 1 foot from top of deflection rulers.
4. Ensure that the operator has sight of four corners of each span tested to measure for possible vertical support movements.

<u>Load Test Setup</u>

1. Start with *UNDERSIDE* measurement of the bridge.
2. Measure (face-face) support span lengths along both edges of bridge, then place mark or nail at midspan location.
3. Measure beam, plank dimensions, and note any unusual repairs.
4. Measure all support bearing lengths for the abutment cap and pier cap beams.
5. Measure (center-center) spacing of all bridge beams at centerspan x-section.
6. Attach brackets and rulers near the center of each beam along the centerspan x-section.
7. Attach brackets and rulers near the support corners (and near centerline for wide bridges) of the span and make sure level instrument can read them ok.
8. Using a plumb bob, transfer the midspan x-section to the deck or curbs.
9. Continue with *TOPSIDE* measurements of the bridge.

10. Measure bridge (out-out) width over planks, and note any overhang at edges.
11. Mark the bridge centerline by using ½ of the bridge width (out-out).
12. Measure the bridge length (out-out) at topside, including all support bearings.
13. Mark truck locations (this point will bisect the rear axles and will be directly between the rear dual wheels) with crayon and paint.
    a. For single lane bridge, use center loading (with wheel lines straddling roadway centerline) with marks at 3 ft on each side of centerline.
    b. For double lane bridge, position truck in each lane in addition to above center loading. Place additional marks 2 ft on each side of centerline.
14. Measure & record truck axle spacing and weights.
15. Commence load test.

<u>Typical Sequence</u>

1. Position truck.
2. Take photograph.
3. Take deflection readings.
4. Check survey level bubble to ensure level.
5. Repeat sequence until testing is complete.

Once all of the data has been collected, it is reviewed briefly before the truck leaves for home. Photographs of the bridge, both end and side views, are then taken with no people, vehicles, or anything else on the bridge. The main components of the setup for load testing can be seen in Figures 3.4, 3.5, and 3.6.

Figure 3.4. Truck positioned on bridge.

Figure 3.5. Deflection rulers.

Figure 3.6. Optical surveying level.

Estimation of Bridge Weight

As known from the theoretical model shown in Equation (3), bridge weight is needed in predicting the structure stiffness using this vibration response method. In this study, bridge weights were estimated based upon actual dimensions along with an estimated unit weight for the timber components. A conservative unit weight of 50 lb/ft^3 (801 kg/m^3) is required for computing dead loads in the design of timber bridges according to AASHTO Standard Specifications for Highway Bridges. A less conservative unit weight of 35 lb/ft^3 (561 kg/m^3), which may more closely represent the actual density of creosote-treated Douglas-fir bridge components, was assumed in computing bridge weights for the field bridges. Douglas-fir was most likely the wood species because visual evidence of incising typically associated with Douglas-fir (and other difficult-to-treat species) was observed at all field bridges.

Chapter 4
Individual Bridge Testing Summary

Bridge 85 Testing Summary

Background

Structure:	Bridge 85
Location:	County Road 258, Duluth, Minnesota
Special Consideration(s):	None
Estimated age:	1946
Inspection date:	July 2005
Construction details:	Two span; heavy timber pilings with Douglas fir girders/stringers and a wood/asphalt deck for a running surface

Bridge Photos:



Vibration Test Data

The vibration testing data for Bridge 85, spans 1 and 2 are shown listed in Tables 4.1 and 4.2.

Table 4.1. Vibration data collected from Bridge 85 for span 1.

				Motor		Vibration Test	
Length (ft)	**Width (ft)**	**C-C Span (ft)**	**Dead load (lb)**	**Speed (rpm)**	**Frequency (Hz)**	**Time/cycle (ms)**	**Frequency (Hz)**
39.4	24.35	18.36	0	1519	25.3	40	25
			0	1571	26.2	38.8	25.7

Note:

- ft = feet, lb = pounds, rpm = revolutions per minute, Hz = hertz, ms = milliseconds

Table 4.2. Vibration data collected from Bridge 85 for span 2.

				Motor		Vibration Test	
Length (ft)	**Width (ft)**	**C-C Span (ft)**	**Dead load (lb)**	**Speed (rpm)**	**Frequency (Hz)**	**Time/cycle (ms)**	**Frequency (Hz)**
18.52	24.3	17.52	1694	28.2	36	27.7	0
			1659	27.7	36.8	27.2	1000
			1706	28.4	35.6	28.1	2000
			1767	29.5	34.8	28.7	2000

Note:

- ft = feet, lb = pounds, rpm = revolutions per minute, Hz = hertz, ms = milliseconds