

Field Performance of Timber Bridges: A National Study

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Summary

As many engineers begin to implement life cycle cost analyses within the preliminary bridge design phase, there is a significant need for more reliable data on the expected service life of highway bridges. Many claims are being made about the expected longevity of concrete and steel bridges being 75 years or more, but few are based on actual performance data. Because engineers are least familiar with timber bridges, their expected longevity is often unfairly estimated at 20 years. A national scale project has been developed for the United States, headed by the USDA Forest Products Laboratory and the U.S. Federal Highway Administration. In this project, national cooperators including Federal Highway Administration, the U.S. Forest Service, Louisiana Department of Transportation, University of Minnesota Duluth, Iowa State University, Mississippi State University, Laminated Concepts, Inc. and Tom Williamson Timber Engineering, LLC will each inspect 15-25 timber bridges, using visual, probing, stress wave, and resistance microdrilling. The study results will help to provide a better understanding of the design, performance, and durability characteristics of timber bridge structures, which can improve future bridge design and preservation practices and ultimately extend service life. Lastly, the findings should assist with timber bridge service life expectancy when compared with alternative bridge materials.

Keywords: timber bridge, inspection, nondestructive evaluation, service life

1. Introduction

1.1 Background

As many engineers begin to implement life cycle cost analyses within the preliminary bridge design phase, there is a significant need for more reliable data on the expected service life of highway bridges. Many claims are being made about the expected longevity of concrete and steel bridges being 75 years or more, but few are based on actual performance data. Because engineers are least familiar with timber bridges, their expected longevity is typically unfairly estimated at 20 years.

Additional research is needed on a national scale that provides more reliable data about the true longevity of timber bridges in the U.S. and allows for more accurate life-cycle assessments.

In order to generate more quantitative and unbiased bridge performance data, the Federal Highway Administration (FHWA) recently launched an initiative called the Long-Term Bridge Performance Program (LTBP). The LTBP is national program and includes detailed inspection, periodic evaluation and monitoring of approximate 200 bridges over a 20-year period [1]. The LTBP program concentrates on “work-horse” highway bridges. This includes steel, reinforced and pre-stressed concrete bridges of stringer/multi-beam or girder, multiple box beam or girders and deck design types constituting 75% to 80% of the National Bridge Inventory (NBI). A representative sample of bridges will be evaluated in a cluster/reference bridge sampling method. Each reference bridge will anchor a cluster of 5 or more bridges that are within a small geographical location (along linear highway corridor or scattered about a geographic region approximately 30 miles wide) and subject to similar climate and traffic conditions. The reference bridges will involve 1) detailed and arm-length visual inspection (VI); 2) advance nondestructive evaluation (NDE); 3) global testing (load testing, modal testing, and continuous monitoring); and, 4) destructive material sampling. The cluster bridges will involve arm-length VI. The LTBP has developed an open, scalable, and extensive data management system called the “Bridge Portal”. This database is capable of integrating LTBP data with other sources, such as NBI, PONTIS, weather, and traffic. Unfortunately, the LTBP currently does not include timber bridges in their current scope. This research study was developed to generate more reliable bridge performance data and establish a framework for long-term timber bridge performance monitoring. This background information will be needed if timber bridges are to be incorporated into the LTBP in the future.

1.2 Timber Bridge Statistics

Timber bridges are an indispensable component of the U.S. highway system especially on secondary rural roadways. The current December 2010 National Bridge Inventory (NBI) database [2] includes 604,426 bridge structures (including culverts) with a span length greater than 20 ft (6 m), with approximately nearly 8 percent utilizing timber as a primary structural component for the superstructure (Table 1). Many of these structures have been in-service for decades and have performed well structurally, but have been deemed structurally deficient or functionality obsolete. In addition, many bridge inspectors are not as familiar with timber as a bridge material and tend to downgrade their condition rating in the NBI. The net result is that many timber bridges have been assigned poor load ratings, or posted for restricted loads, when their actual condition is satisfactory. The long-range impact is that many engineers hold the misconception that timber is a low performance bridge material having an estimated service life of less than 20 years.

Table 1 – NBI bridge statistics as of December 2010.

Concrete	Steel	Timber	Masonry	Aluminum	Other	Total
391,161	185,148	24,267	1,743	1,459	648	604,426
All timber superstructure		Timber deck on steel stringers		Total		
24,267		24,492		48,759 (8% of total)		

There are promising examples of length-of-service that support the long-term durability of timber bridges. The Forest Service (FS) maintains nearly 3,000 timber road bridges in their transportation network. Many of them are sawn timber superstructures that were installed in the post-WWII era and are still in-service after several decades. The FS also has a fairly large population of early glulam bridges built in the 1950s that are still providing vital transportation links in the Pacific Northwest. The railroads have used timber components for bridges for over 100 years and have several sawn timber

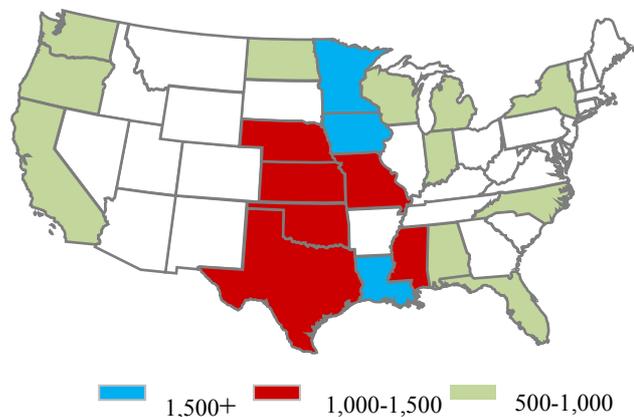


Figure 1 – States with a significant number of timber bridges in their bridge inventory.

structures that have been in-service for more than 75 years. However, what is lacking in the literature is a scientific study on the long-term performance of timber highway bridges in the U.S.

The geographical distribution of the NBI inventory data shows that 19 States have greater than 500 bridges (Figure 1). States with more than 1,500 timber bridges include Louisiana, Iowa, and Minnesota. States having 1,000–1,500 timber bridges include Texas, Oklahoma, Mississippi, Kansas, Missouri, and Nebraska. States having 500–1,000 bridges include North Dakota, California, Oregon, Washington, Wisconsin, Michigan, Indiana, Alabama, New York, North Carolina, and Florida. The remaining 31 States have less than 500 timber bridges in their respective inventory.

There are a variety of timber bridge superstructure types. The main categories are longitudinal decks, stringer systems, and others. Longitudinal decks include nail-laminated, spike-laminated, stress-laminated (using either sawn lumber or glulam laminations), and longitudinal glulam bridges. The spike-laminated and longitudinal glulam deck superstructures consist of partial width panels that are interconnected with transverse stiffener beams attached at intervals along the bridge length. Stringer systems include sawn lumber, glulam, steel, and fiber-reinforced polymer (FRP) glulams. Other timber bridge superstructures include arches, trusses, and cable-supported structures. Photographic examples of several timber bridge superstructure types are provided in Figure 2.

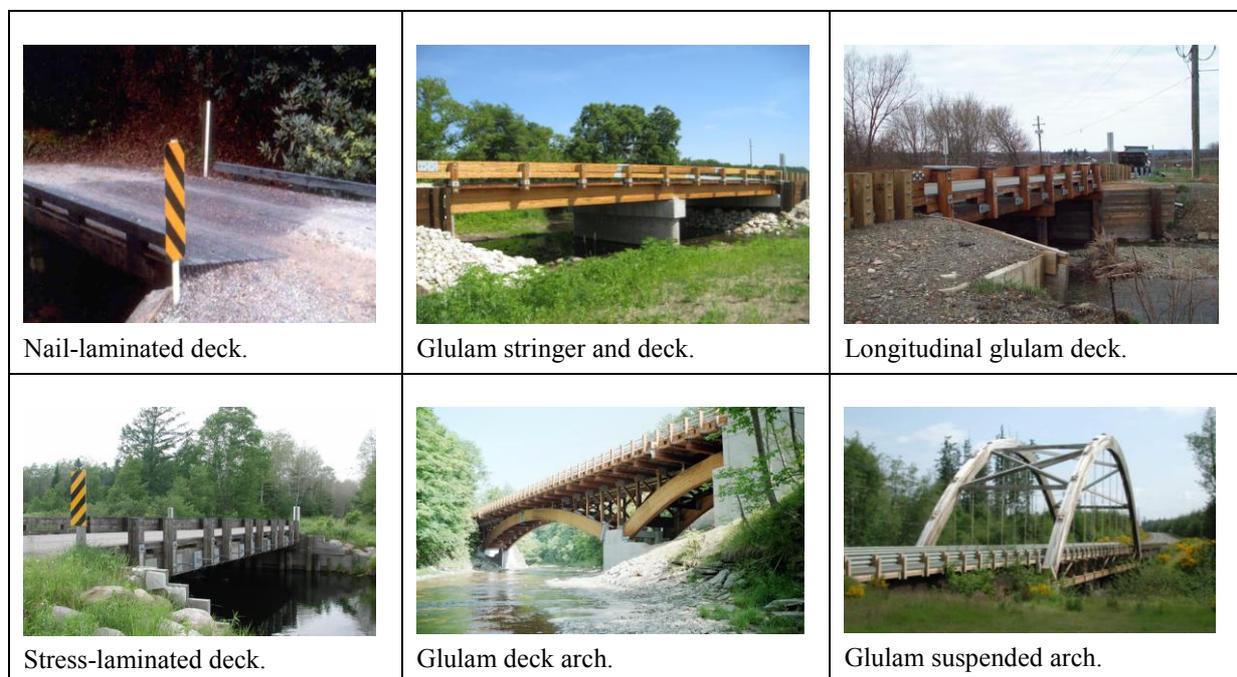


Figure 2 – Photographic examples of various timber bridge superstructures.

1.2 Objective and Scope

The primary objective of this study was to assess the condition and performance of approximately 100 existing timber highway bridges representing the main climate regions in the continental United States. A secondary objective of this study was to establish the baseline framework for evaluating future performance of timber bridges nationwide. The study results will help to provide a better understanding of the design, performance, and durability characteristics of timber bridge structures, which can improve future bridge design and preservation practices and ultimately extend service life. Lastly, the findings should assist with timber bridge service life expectancy when compared with alternative bridge materials.

2. Research Methods

2.1 Project Team Overview

The overall project was jointly managed by James Wacker of the Forest Products Laboratory (FPL) and Frank Jalinoos of the Federal Highway Administration (FHWA). The regions that were

selected for bridge inspection were based on the American Wood Protection Association (AWPA) wood decay hazard map shown in Figure 3. In order to assess these regions, a diverse project team was created that included: Tom Williamson Timber Engineering LLC, Rogue River-Siskiyou National Forest, Iowa State University, University of Minnesota Duluth, Mississippi State University, Louisiana Transportation Research Center, and Laminated Concepts Inc. Each organization represented a U.S. region and would be responsible for inspecting bridges in their respective regions. Figure 3 also shows the general geographic region for each organization.

A project kickoff meeting was held in Madison, Wisconsin and included several presentations and discussions with a goal of providing project information on bridge selection, inspection protocols, safety guidelines, and data processing for the project. All teams received information on inspection protocols and equipment. An inspection demonstration was completed on a timber bridge.

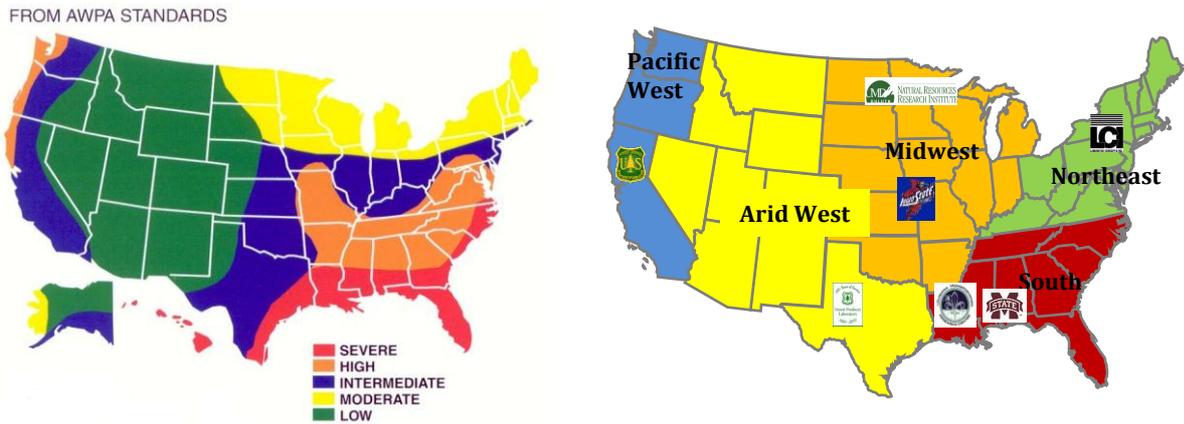


Figure 3 – Wood decay hazard map and team inspection assignments in the continental U.S.

2.2 Bridge Selection

Team members were asked to assess the inventory of timber bridges in their region and select candidate bridges for field evaluations. Teams were required to select timber bridge clusters within a multi-county region that had the same superstructure design type and were preferably of similar age. Each project team selected 15-25+ bridges for inspection. This list was reviewed and approved by the project coordinators and used to assemble a national perspective for the candidate bridge selections and determine age and bridge type overview.

Teams used several options for identifying candidate bridges within their region. The National Bridge Inventory (NBI) [2] should be the primary source for identifying timber bridge populations by state and county. A good resource for navigating the NBI database is available at the National Bridges internet portal [3]. It is a non-governmental website based on December 2012 NBI figures and allows for rapid data sorting and downloading to spreadsheets for additional analysis. Another effective method was to contact specific counties that have a sizable population of timber bridges directly. In most cases, they have developed their own bridge database separate from any NBI requirements.

The criteria for the selection of timber bridges included the following requirements:

- Bridge superstructure must consist of timber as structural component;
- The timber bridge must be located on a public roadway;
- The timber bridge must have been in-service for more than 15 years;
- Background files must include adequate records about the design, inspections, and major repairs;
- Accessibility for conducting an “arm’s length” bridge inspection in a safe manner;
- In selecting reference bridge clusters, vicinity to a WIM station for ADT data and to a weathering station for temperature/moisture records is desirable.

Teams were encouraged to conduct pre-inspection site visits to confirm the inspection location and understand the site conditions include key parameters like traffic conditions, depth of water and vertical distance from bridge underside to water.

2.3 Bridge Inspection

Each team conducted their bridge inspection using the same protocol that was provided during the kick-off meeting and in the detailed study plan. This ensured that a reliable dataset was produced regarding the performance of timber bridges. The recommended protocols for pre-inspection, general inspection, and NDE inspection are described below.

2.3.1 Pre-Inspection Protocol

Prior to inspection, a careful review of design plans and any prior inspection and maintenance work was recommended. This identified bridge areas that have been problematic in the past. These areas were then a focus area during the project inspection. Teams were also encouraged to interview the bridge owner about the bridge and any previous problems noted and to obtain previous reports.

Methods for recording inspection work included digital photographs, sketches/diagrams, and tabulated NDE data. Based on the NBI data or design drawings (or recent as-built drawings, if available) it was recommended that schematic drawings (plan, profile, and section) were developed along with tabulated data sheets. Tracking the location of data collection points was critically important. Photos were taken with high-resolution digital cameras and not compressed when inserted into the report files. A detailed spreadsheet template was provided for all inspection teams to assist with creating consistent data. This spreadsheet had the following sheets: inspection checklist, bridge information, raw data and sketches, bridge photos, reduced data, NBI ratings, inspection and maintenance history.

2.3.2 Inspection Protocol

Inspection procedures included visual observations and supplementary NDE tools including hammer, probe, moisture meter, stress wave timer, and resistance microdrill. Detailed information about these procedures is noted in section 2.4 of this paper. All data was documented through onsite sketches, photos and video.

2.3.3 Topside Inspection Process

Specific field tasks were provided for the topside inspection.

1. Record the bridge location and orientation of the timber bridge. Drawings should be marked for principal directions and stream flow.
2. Visually inspect wearing surface for problems.
3. Visually inspect the rail and curb system for problems.

2.3.4 Bottom side Inspection Process

Specific field tasks were provided for the bottom side inspection.

1. Label bridge components prior to inspection and photographic documentation. Abutments should be labeled BOB (beginning of bridge) and EOB (end of bridge). Girders should be labeled A, B, C, etc. with A on the upstream side of the bridge.
2. Conduct an initial visual assessment and use a hammer for “sounding” bridge components. Record locations with visible deterioration and mark those areas suspected of internal deterioration, so further investigation using NDE tools can be performed.
3. Conduct a survey of moisture contents in typical areas prone to decay (bridge ends, tops of stringers, etc.) to identify areas conducive to decay activity with mc levels above 20 percent. Readings should be taken at pin penetrations of 1-, 2-, and 3-inches at each location.
4. Record the types of preservative treatment used and describe how well it has performed. This information may be documented on bridge plans.
5. Establish baseline NDE data, by using the stress wave timer and resistance microdrill unit in an area of the bridge with no expected internal deterioration. This will be useful in comparing NDE data from other areas with various levels of internal deterioration.

6. Investigate all suspected areas using a two-step approach. Utilize the stress wave timer when you have access to opposite sides of a member. Record the transmission distance and the resulting transit time (microseconds). When stress wave data is significantly higher than baseline values, or when only one side of a bridge component is accessible, use the resistance microdrill unit. Make sure to record the location of all data points and drilling locations (and file no.) on drawing or sketches.

2.3.5 Performance Data and NBI Ratings

1. Identify performance issues that caused decay or poor performance addressing design type, construction quality, durability, serviceability, functionality, and structural integrity.
2. Determine possible causes for decay or poor performance.
3. Assign NBI ratings for the bridge deck and superstructure according to the NBI bridge condition code rating description shown in Table 2.

Table 2 – NBI bridge condition code ratings description.

FHWA - SI&A Sheet Condition Rating Code	FHWA - SI&A Sheet Condition Rating Description
N	NOT APPLICABLE
9	EXCELLENT CONDITION - New or like new condition.
8	VERY GOOD CONDITION - No problems noted.
7	GOOD CONDITION - Some minor problems but no structural defects at critical locations (wood decay is a defect).
6	SATISFACTORY CONDITION - Structural elements show some minor defects and/or deterioration at critical locations. No measureable section loss.
5	FAIR CONDITION - All primary structural elements are sound but may have minor to moderate defects and/or deterioration with measurable section loss at critical locations. No significant reduction in primary structural member load carrying capacity.
4	POOR CONDITION - Primary structural elements show moderate to serious defects, deterioration, corrosion, cracking, crushing, and/or scour. Advanced section loss at critical locations. Diminished load carrying capacity of members is evident.
3	SERIOUS CONDITION - Serious and widespread defects have substantially reduced load carrying capacity of primary structural members. Local failures may be evident. Deflection/misalignment of members may be evident. Signs of severe structural stress are visible. Fatigue cracks in steel, shear cracks in concrete, and severe decay, checking, splitting, and crushing of beams or stringers in wood elements may be present.
2	CRITICAL CONDITION - Advanced deterioration of primary structural elements. Defects have now resulted in significant local failures. Scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken.
1	IMMINENT FAILURE CONDITION - Major deterioration or section loss present in critical structural components and/or obvious vertical or horizontal movements affecting structure stability. Bridge is/should be closed. However, correction action may put bridge back in light service.
0	FAILED CONDITION - Out of service. Beyond corrective action.

2.4 Nondestructive Inspection Techniques

Comprehensive inspection protocols for timber bridges include a wide variety of techniques to assess the condition of wood in service. Visual, moisture content, mechanical probing, resistance microdrilling and stress wave or ultrasound-based technologies are all used individually or in combination by inspectors [4], [5], and [6]. These techniques are based on solid technical information, supporting research, and field experience. The following sections provide background information for visual inspections, moisture content, mechanical probing, resistance microdrilling and stress wave or ultrasound-based technologies that were incorporated into inspection protocols.

2.4.1 Visual Inspection

The simplest method for locating deterioration is visual inspection. An inspector observes the bridge elements for signs of actual or potential deterioration, noting areas that require further

investigation. 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 should be investigated: fruiting bodies, sunken faces or localized collapse, staining or discoloration, insect or animal activity, plant or moss growth, checks and splits, weathering or impact damage, or rotation of members. Figure 4 shows several visual indicators evident during bridge inspection.

2.4.2 Drilling, Coring and Probing Techniques

Simple mechanical tests are frequently used for in-service inspection of wood members in timber bridge structure. For example, probing or drilling-type tests are used to examine the condition of a structural member that is identified as potentially having decay or deterioration. Further, the use of probes can allow the inspector to determine the depth of any checks or splits. The underlying premise for such tests is that degraded wood is relatively soft and will have low resistance to probe penetration or withdrawal.



Figure 4 – Visual inspection conditions including discoloration and staining, insect activity, mechanical damage and build-up of sand and gravel.

Probing with a moderately pointed tool, such as an awl or knife, locates decay near the wood surface as indicated by excessive softness or a lack of resistance to probe penetration and the breakage pattern of the splinters. A brash break indicates decayed wood, whereas a splintered break reveals sound wood. Although probing is a simple inspection method, experience is required to interpret results. Care must be taken to differentiate between decay and water-softened wood that may be sound but somewhat softer than dry wood. Probes can also be used to assess the depth of splits and checks in timber bridge elements. Flat bladed probes like pocket knives or feeler gauges are recommended for use in this process. It is important to understand the impact of checks and cracks in other advanced techniques such as stress wave inspection.

Another drilling technique that has been commercially developed is the resistance drill system. This system was originally developed for use by arborists and tree care professionals to evaluate the condition of urban trees and locate voids and decay. It is now being utilized to identify and quantify decay, voids, and termite galleries in wood stringers, columns, poles, and piles. This technique is now the preferred drilling and coring technique for timber bridge elements.

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



Figure 5 – Resistance microdrilling techniques were used to inspect timber bridge elements.

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. Figure 5 shows a timber abutment cap being assessed with a resistance microdrill and the resulting chart image showing minimal drilling resistance that indicating that the majority of the cap is decayed.

2.4.3 Moisture Content Inspection

Moisture meters can effectively be used in conducting inspections of timber bridge elements. It is well documented that the presence of moisture is required for decay to occur in timber. Typically, moisture conditions in timber of less than 20% will not allow decay to occur. However, as the moisture increases above 20%, the potential for decay to occur increases. Serious decay occurs only when the moisture content of the wood is above 28-30%.

2.4.4 Stress Wave Inspection

Stress wave timing is an effective method for locating and defining areas of decay in timber bridges. Stress wave propagation in wood is a dynamic process that is directly related to the physical and mechanical properties of wood. In general, stress waves travel faster in sound and high quality wood than in deteriorated and low quality wood. By measuring wave transmission time through a timber bridge stringer, pile cap or piling in the radial direction, the internal condition of the structural element can be fairly accurately evaluated. As an introduction, a photograph and schematic of the stress wave concept for detecting decay in a timber piling are shown in Figure 6. A stress wave is induced by striking the timber member with an impact device or with an ultrasonic pulse instrumented with an accelerometer that emits a start signal to a timer. A second accelerometer, held in contact with the other side of the timber member, senses 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. This measured time, when converted to a transmission time on a per length basis (or wave propagation speed), can be used as a predictor of the physical conditions inside the timber bridge member.

Stress wave transmission times are shortest along the grain (parallel to fiber) and longest across the grain (perpendicular to fiber). For common timber bridge species Douglas fir and southern pine at dry conditions, stress wave transmission time is approximately $200 \mu\text{s}/\text{m}$ ($60 \mu\text{s}/\text{ft}$) parallel to grain, but ranges from 850 to $1000 \mu\text{s}/\text{m}$ (259 to $305 \mu\text{s}/\text{ft}$) in the perpendicular or cross-grain direction. The presence of deterioration from decay can greatly affect stress wave transmission time in wood. Transmission times for decayed wood are much greater than that for nondecayed wood. For example, transmission time for nondegraded Douglas fir is approximately $800 \mu\text{s}/\text{m}$ ($244 \mu\text{s}/\text{ft}$), whereas severely degraded members exhibit values as high as $3,200 \mu\text{s}/\text{m}$ ($975 \mu\text{s}/\text{ft}$) or greater.

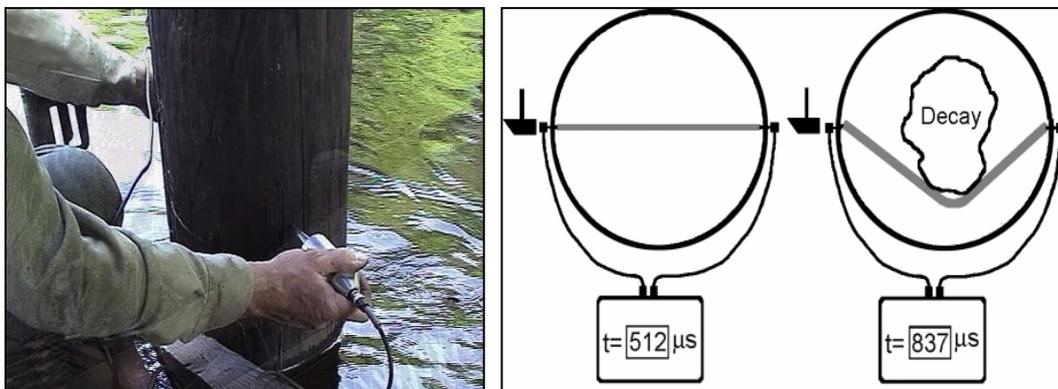


Figure 6 – A stress wave timer is used to inspect timber bridge elements to identify the presence of internal decay that is not visible.

3. Upper Midwest Inspection Region

3.1 Bridge Selection

The UMD project team was responsible for the upper Midwest. Minnesota has over 1,500 bridges and Wisconsin has between 500 and 1,000 bridges containing timber superstructure members. Both states are located in AWWPA wood decay deterioration zone 3 - moderate. The project team selected bridges based on type and then focused the inspection in one -three adjoining counties.

Specifically, the team selected solid sawn timber stringer, glulam timber stringer, steel stringer with timber deck, and spike-laminated deck bridge systems for inspection. The solid sawn timber stringer bridges were located in two separate geographic locations. One set was owned and maintained by the USDA Forest Service Chequamegon-Nicolet National Forest in northern Wisconsin. The second set was owned and maintained by Freeborn, Faribault and Jackson Counties in southern Minnesota. The glulam timber stringer bridges were owned and maintained by Faribault County in southern Minnesota, while the steel stringer timber deck and spike laminated bridges were owned and maintained by St. Louis County in northern Minnesota. The average climate data for northern Wisconsin shows annual precipitation of 33-34 inches [7]. The normal annual precipitation amounts for northern Minnesota are 28-30 in and from 29-33 in. in southern Minnesota [8]. Table 3 provides detailed information about the bridges selected for inspection.

Table 3 – Timber bridges inspected in the upper Midwest region during the project.

County/ ID	Superstructure Type	Year Built	Span/ Lengths m (ft)	Average Daily Traffic	Width m (ft)	Wearing Surface	Substructure Material
Freeborn/ 8587	Solid sawn timber stringer	1946	6.0 (19.8)	51	7.4 (24.4)	Gravel over timber deck	Timber piling
Faribault/ 22512	Solid sawn timber stringer	1967	9.1 (30)	67	8.4 (27.5)	Bituminous over timber deck	Timber piling
Jackson/ 5937	Solid sawn timber stringer	1940	9.4, 9.4, 9.4 (31)	1,050	8.5 (28)	Bituminous over timber deck	Timber piling
Jackson/ 5938	Solid sawn timber stringer	1940	9.4 (30), 10.4 (34)	1,050	8.5 (28)	Bituminous over timber deck	Timber piling
Taylor/FS 108-05.3	Solid sawn timber stringer	1980	7.3 (24)	50	7.9 (26)	Timber plank	Timber piling
Taylor/FS 112-4.1	Solid sawn timber stringer	1953	5.2 (17)	30	4.6 (15)	Timber plank over laminated deck	Timber piling
Price/FS 147-1.3	Solid sawn timber stringer	1956	4.9 (16)	20	4.6 (15)	Timber plank	Timber piling
Ashland/ FS/ 164-24.3	Solid sawn timber stringer	1953	7.7 (25.3)	20	4.9 (16)	Timber plank	Timber piling
Faribault/ 22508	Glulam timber stringer	1968	10.2 (33.5)	95	10.1 (33.3)	Bituminous over timber deck	Timber piling
Faribault/ 22514	Glulam timber stringer	1968	12.2 (40)	35	7.9 (26)	Gravel over timber deck	Timber piling
Faribault/ 22518	Glulam timber stringer	1969	11.7 (38.5)	70	10.1 (33.1)	Gravel over timber deck	Timber piling
Faribault/ 22519	Glulam timber stringer	1969	10.2 (33.5)	539	9.7 (32)	Bituminous over timber deck	Timber piling
Faribault/ 9967	Glulam timber stringer	1951	11.0 (36.2)	175	8.4 (27.4)	Bituminous over timber deck	Timber piling
St. Louis/ 540	Spike laminated deck	1991	5.4, 5.4, 5.4 (17.8)	519	11.6 (38)	Bituminous over timber deck	Steel H piling

St. Louis/ 497	Spike laminated deck	1988	4.3, 5.5, 4.3 (14, 18, 14)	230	10.4 (34)	Bituminous over timber deck	Cast in place (CIP)
St. Louis/ 221	Spike laminated deck	1981	5.3, 7.0, 5.3 (17.5, 23, 17.5)	95	10.4 (34)	Bituminous over timber deck	Cast in place (CIP)
St. Louis/ 611	Spike laminated deck	1985	6.6, 6.6, 6.6 (21.8)	245	10.4 (34)	Bituminous over timber deck	Timber piling
St. Louis/ 92	Steel stringer timber deck	1978	8.7 (28.6)	80	8.7 (28.5)	Bituminous over timber deck	Timber piling
St. Louis/ 185	Steel stringer timber deck	1983	10.7 (35)	40	9.1 (30)	Bituminous over timber deck	Timber piling
St. Louis/ 194	Steel stringer timber deck	1977	9.5 (31)	35	7.3 (24)	Bituminous over timber deck	Timber piling
St. Louis/ 197	Steel stringer timber deck	1971	9.5 (31)	35	7.3 (24)	Bituminous over timber deck	Timber piling
St. Louis/ 811	Steel stringer timber deck	1987	10.0 (32.8)	4	6.7 (22)	Timber deck	Timber piling

3.2 Inspection Results

Detailed inspections were completed using visual, moisture content, mechanical probing, resistance microdrilling and stress wave or ultrasound-based techniques. Sketches were completed on site for each bridge inspected and they were later converted to AutoCAD images for record keeping. High resolution digital photographs were taken of the bridge with special emphasis on deteriorated or damaged areas. Raw data from stress wave timer and resistance drill were processed and recorded. Information was obtained from the bridge owner on previous inspections with special emphasis on any repairs or modifications to the bridge. Finally, the inspection team rated the bridge according to NBI ratings.

3.2.1 Solid Sawn Timber Stringer Bridges

Two sets of solid sawn timber stringer bridges were inspected. One group was located in northern Wisconsin and owned and maintained by the US Forest Service Chequamegon-Nicolet National Forest. The superstructures for these bridges were solid sawn, creosote treated Douglas fir stringers, with most having timber decking and timber rails. The NBI ratings assigned by the UMD NRRRI team are shown in Table 4. The data for each bridge is reported along with the mean ratings for the group. It was found that the vast majority of the superstructure stringers were in satisfactory to good condition. There was minimal evidence of decay or deterioration in the stringers, but there was cracking and checking present in the outermost stringers that were exposed to weathering. Often, there was frequent mechanical damage to the railings caused by snowplows, road graders or other vehicles.

Table 4 – NBI condition ratings for the solid sawn stringer bridges inspected in northern Wisconsin.

NBI Condition Rating	Bridge Number				Group Mean
	USFS/ 108-5.3	USFS/ 112-4.1	USFS/ 147-1.3	USFS/ 164-24.3	
Deck	5	4	6	5	5
Superstructure	7	6	6	6	6.3

The second set of solid sawn timber stringer bridges was inspected in southern Minnesota. Three of the four bridges had a bituminous wear layer over timber decks and one had gravel over a timber deck. The decking was in generally good condition, with some deterioration and cracking in the bituminous wear layer, allowing for water infiltration. The solid sawn stringers were solid sawn, creosote treated Douglas fir stringers. The majority of the stringers were in good to satisfactory condition, but Freeborn 8587 had several significantly decayed girders. This bridge is slated for replacement in 2014. The NBI ratings assigned by the UMD NRRRI team are shown in Table 5.

Table 5 – NBI condition ratings for the solid sawn stringer bridges inspected in Minnesota.

NBI Condition Rating	Bridge Number				Group Mean
	Freeborn/ 8587	Faribault/ 22512	Jackson/ 5937	Jackson/ 5938	
Deck	5	6	7	7	6.3
Superstructure	5	6	7	7	6.3

3.2.2 Glulam Stringer Bridges

A set of 5 glulam stringer bridges was inspected in Faribault County, Minnesota. Most of these single span glulam bridges were constructed in late 1960s and had creosote treated southern yellow pine stringers. These stringers did not contain modern fingerjoint construction within each laminate layer, but a modified scarf joint. Each of the bridges had a nail laminated timber deck with a bituminous wear layer. These stringers were found to be in excellent condition as inspected using visual, sounding, and stress wave inspections. The bituminous wearing surfaces showed cracking, allowing water to infiltrate through the deck. There were no high moisture conditions identified in the glulam stringers. The NBI ratings assigned by the UMD NRRI team are shown in Table 6.

Table 6 – NBI condition ratings for the glulam stringer bridges inspected in southern Minnesota.

NBI Condition Rating	Bridge Number					Group Mean
	Faribault/ 22508	Faribault/ 22514	Faribault/ 22518	Faribault/ 22519	Faribault/ 9967	
Deck	7	6	7	6	7	6.6
Superstructure	7	7	7	7	6	6.8

3.2.3 Spike Laminated Deck Span Bridges

Four spike laminated deck span bridges were inspected in St. Louis County, Minnesota. These bridges had been mostly constructed in the 1980s. These bridges were constructed of panels manufactured by Wheeler Consolidated. The main structural material was creosote treated Douglas fir. The bridges all had a bituminous wear layer over the spike-laminated deck. The wear layers showed significant cracking and deterioration in some cases. However, there was no decay or deterioration noted in the inspection of the superstructure. The railing systems showed some damage and deterioration from snowplows, road graders or other vehicles. The NBI ratings assigned by the UMD NRRI team are shown in Table 7.

Table 7 – NBI condition ratings for the spike laminated bridges inspected in northern Minnesota.

NBI Condition Rating	Bridge Number				Group Mean
	St. Louis/ 540	St. Louis/ 497	St. Louis/ 221	St. Louis/ 611	
Deck	5	5	5	4	4.8
Superstructure	7	7	7	5	6.5

3.2.4 Steel Stringer Timber Deck Bridges

Five steel stringer timber deck bridges were inspected in St. Louis County, Minnesota. These single span bridges were constructed from 1971 - 1987. The steel stringers were the main structural superstructure and four of the bridges had a nail laminated treated timber deck with a bituminous wear layer. The fifth bridge had a nail laminated timber deck without a bituminous wear layer. The bridges were in satisfactory to good condition according to the NBI condition rated completed. The bituminous wear layer showed cracking and deterioration on most bridges. Visual inspection, hammer sounding and probing of the decking showed it to be in satisfactory condition. The steel stringers showed some peeling paint and minor rust. The NBI ratings assigned by the UMD NRRI team are shown in Table 8.

Table 8 – NBI condition ratings for the steel stringer timber deck bridges inspected in Wisconsin.

NBI Condition Rating	Bridge Number					Group Mean
	St. Louis/ 92	St. Louis/ 185	St. Louis/ 194	St. Louis/ 197	St. Louis/ 811	
Deck	7	6	6	6	6	6.2
Superstructure	8	7	7	7	7	7.2

4. Conclusions

The purpose of this project was to create a timber bridge assessment project resulting in the inspection of approximately 100 timber vehicle bridges over 15 years old. These bridges were to be inspected using visual, probing, moisture content, stress wave, and resistance microdrilling. Completion of this work will help provide a better understanding of the design, performance, and durability characteristics of timber bridge structures, leading to improvements in future bridge design and preservation practices and ultimately extended service life. The following conclusions were evident from the testing, analysis, and data interpretation of the project to date:

- Approximately 100 bridges were inspected across the U.S. that had structural timber in their superstructure. Detailed arms length inspections were completed using visual, sounding, probing, moisture content, stress wave timing and resistance drilling techniques. Varied performance was identified for these bridges based on age, AWPA wood decay zone, and maintenance level.
- The majority of bridge superstructures inspected were stringer systems with solid sawn timbers. Additional groups of bridges assessed included glulam stringer, steel stringer timber deck, and longitudinal deck systems. Decks systems included sawn, nail laminated and glue laminated timber decks.
- Ongoing assessment and interpretation of the project results will be completed and reported in the next 9 months.

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