Condition Assessment of Iowa Timber Bridges Using Advanced Inspection Tools

Travis Hosteng
Research Engineer
Bridge Engineering Center
Iowa State University
Ames, IA United States
kickhos@iastate.edu

Travis earned his MSc degree from Iowa State University. He is the lead engineer for wood bridge projects at the BEC. He is also a member on the ASCE committee for timber bridges.

James Wacker
Research Engineer
Forest Products Laboratory
Madison, WI United States
jwacker@fs.fed.us

Jim earned his Civil Engineering degree from the University of Wisconsin. He is a registered professional engineer with more than 20 years' experience in timber bridge research.

Brent Phares
Director
Bridge Engineering Center
Iowa State University
Ames, IA United States
bphares@iastate.edu

Brent is the Director of Iowa State University's Bridge Engineering Center. He is regarded as an international expert in the field of advanced bridge evaluation technologies.

Summary

This paper reports the results of a study undertaken to assess the condition of timber bridges in the state of Iowa. This study was carried out as part of an overall national study spearheaded by the Forest Products Laboratory and FHWA to investigate the field performance of timber bridges throughout the United States. In the U.S., Iowa has the most timber bridge structures at more than 2,500. The inspection team utilized advanced NDE assessment tools such as the resistance micro-drill and other acoustic devices to evaluate the condition of the suspect areas of the timber sub- and superstructure elements. The three clusters of timber bridges were selected by the Forest Products Laboratory to ensure that they are representative of the various types of timber bridges in the state and matched other sets of bridges in other climatic regions of the U.S. Detailed results of the inspection conducted on these three bridge clusters in Iowa are presented. These results will provide a better understanding of the design, performance, and durability of timber bridges and their components in the state of Iowa.

Keywords: inspections; NDE, timber, bridge, field performance

1. Introduction

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 conservatively estimated at 20-30 years. Additional research is needed on a national scale that provides more reliable data about the true longevity of timber bridges in the US 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 a new initiative called the Long-Term Bridge Performance Program (LTBP). The LTBP is a national program and it includes detailed inspection, periodic evaluation and monitoring of approximate 200 bridges over a 20-year period. 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 slab design types constituting 75% to 80% of the National Bridge Inventory (NBI). Under the LTBP program, a representative sample of bridges was evaluated in a cluster/reference bridge sampling method. Each reference bridge anchors a cluster of 5 or more bridges which are within a small geographical location (along a linear highway corridor or scattered about a geographic region approximately 30 miles wide) and subject to similar climate and traffic conditions. Evaluation of the reference bridges involves 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 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. A new research study aimed at generating more reliable bridge performance data and establishing a framework for long-term performance monitoring will be needed if timber bridges are to be incorporated into the LTBP in the future.

The following briefly discusses the three bridge clusters inspected in Iowa, an overview of the findings of those inspections, and discussion of the overall process.

2. Iowa Timber Bridge Inventory

2.1 Inventory Statistics

The state of Iowa has, according to the most recent NBIS listing, 2,454 timber bridges. Of those, approximately 189 are timber slab bridges, and the remaining are timber girder bridges. The timber slab bridges range in age from about 4-65 yrs, with the majority built after 1990; the inventory of timber girder bridges range in age from about 3 yrs to nearly 100 yrs old and the majority of those were built between 1940 and 1990.

2.2 Selected Clusters

Critical elements desired of the cluster bridges during the selection process included: a) bridge superstructure consists of timber as structural component, b) bridge located on public roadway, c) accessibility for safely conducting ‘arm’s length’ bridge inspection, d) bridges within a cluster should be of same superstructure design type and preferably of similar age. Additionally, to simplify things logistically, once an age range of bridges was selected for a given bridge type, the list was further subdivided by county to make travel and inspection of the respective clusters more efficient. Three clusters of bridges were selected from the inventory of timber bridges in Iowa. Since timber girder bridges represented the largest percentage of timber bridges in Iowa, two of the three clusters were selected from that inventory, and the third cluster was selected from the timber slab inventory. A brief description of each cluster and its constituents is provided here, in addition, a sample bridge inspection from each cluster is also provided in Section 4 of this report.

2.2.1 Iowa Cluster Geography

The three Iowa clusters were located in Bremer, Blackhawk and Clarke Counties, which are highlighted in Fig. 1. Bremer and Blackhawk Counties are in the Northeast part of the state, and Clarke is in the South central part of the state.

Fig. 1. Iowa county locations for inspections.

2.2.2 Cluster 1 Details

The five timber bridges located in Bremer County, Iowa were all single span, timber girder bridges with transverse timber plank decks and were located on secondary gravel roads. All five of the bridges were built between 1994 and 1997 and the superstructure elements consisted of Douglas-fir timber treated with creosote. Each bridge consisted of between 25 - 35 timber girders measuring 102 mm (4 in.) x 406 mm (16 in.) and the timber planks were 102 mm (4 in.) x 305 mm (12 in.) which were nailed to the tops of the girders. All of the bridges had timber abutments consisting of timber piles, plank backwalls/wingwall and timber caps and timber guardrails. The ends of the girders were typically nailed to the timber plank backwall as well as toe nailed to the solid timber abutment caps. See Figs. 2 and 3 for a typical bridge layout.

Fig. 2 Timber girder bridge elevation view from Cluster 1 in Bremer County

Fig. 3 Timber girder bridge underside view from Cluster 1 in Bremer County

2.2.3 Cluster 2 Details

The five timber bridges located in Blackhawk County, Iowa were also all single span, timber girder bridges with transverse timber plank decks and were located on secondary gravel roads. One bridge, Blackhawk 3, was on an approximately 20 degree skew, all other bridges had no skew. All five of these bridges were built between 1983 and 1985 and the superstructure elements consisted of Douglas-fir timber treated with creosote. Each bridge consisted of 19 or 28 timber girders ranging in dimensions of 152 mm (6 in.) x 406 mm (16 in.) for the bridge with 19 girders and 102 mm (4 in.) x 406 mm (16 in.) for the four bridges with 28 girders. Timber planks on these bridges were typically 102 mm (4 in.) x 305 mm (12 in.) and were nailed to the tops of the girders. All of the bridges had timber abutments consisting of timber piles, plank backwalls/wingwall and timber caps. Four of the bridges had steel guardrails and the fifth, shown in Fig. 4, had timber rail posts with thrie beam rail. The ends of the girders were typically nailed to the timber plank backwall as well as toe nailed to the solid timber abutment caps. See Fig. 5 for a typical bridge layout.

Fig. 4 Timber girder bridge elevation view from Cluster 2 in Blackhawk County

Fig. 5 Timber girder bridge underside view from Cluster 2 in Blackhawk County

2.2.4 Cluster 3 Details

The five timber bridges located in Clarke County, Iowa were all single span, longitudinal timber deck bridges with a single transverse timber stiffner beam located at midspan. All five of these bridges were built between 1982 and 1985 and the superstructure elements consisted of Douglas-fir timber treated with creosote. Each bridge consisted of nail-laminated timber plank sections made up of individual timbers approximately 76 mm (3 in.) to 102 mm (4 in.) x 357 mm (14 in.). The individual deck sections were then joined together with a longitudinal lap joint and galvanized dome head bolts. Gravel provided the wearing surface for four of the bridges located on secondary gravel roads; Clarke 1, which was located in a small town, was covered with an asphalt wearing surface. All of the bridges had timber abutments consisting of timber piles, plank backwalls/wingwall and timber caps, as well as timber guardrails and timber curbs with scuppers. See Figs. 6 and 7 for a typical bridge layout.

Fig. 6 Timber deck bridge elevation view from Cluster 3 in Clarke County

Fig. 7 Timber deck bridge underside view from Cluster 3 in Clarke County

2.3 Decay Hazard Zones

There are 5 decay hazard zones located throughout the United States, Zone 1 being the lowest risk, Zone 5 being the highest risk. The two clusters of bridges in Bremer and Blackhawk Counties are approximately on the boarder of Zones 2 and 3, whereas the bridge cluster in Clarke County is most likely a Zone 4 classification.

3. Inspection Methods

3.1 Pre-Inspections

Inspection of each bridge was a multi-phase process initiated in the office prior to field inspections. Once the bridges within each cluster had been selected, previous inspection records were searched for and downloaded from the Iowa DOT Structure Inventory and Inspection Management System (SIIMS). These inspection reports were carefully reviewed to obtain background knowledge regarding the history of the bridge, confirm dimensions, note any deficiencies, and gather as much preliminary information pertaining to the bridge as possible. Once the inspection reports had been combed through and the research team had confirmed that the subject bridges were quality candidates for full inspection, the county engineer for each cluster was contacted. Any additional information available from the county engineer was collected, and reviewed and permission to conduct a full inspection was requested (and graciously accepted by all entities). In addition, all counties involved were gracious enough to provide existing, or obtain new, photos of the bridges for use in the recon process and determination of access limitations.

3.2 Inspection Methodology

Inspection guidelines and recommendations along with details on specific information required to be collected during the inspection were outlined by the project advisory committee for all inspection regions. Below is a condensed summary of the tasks and information collected during all inspections:

- Bridge orientation, location
- Top side inspection (wearing surface, curb, guardrails, approaches, etc.)
- Label and photograph superstructure elements
- Collect additional required bridge photographs
- Conduct initial visual inspection (hammer sounding)
- Collect moisture content information
- Investigate areas of potential decay/damage with advance NDE equipment
    - Stress-wave timer
    - Resistograph
- Record all bridge dimensions, NDE evaluation locations, and areas of decay/damage
- Upload inspection data to spreadsheet/website database

Prior to investigating areas of potential deterioration, an area considered to be sound material was investigated to provide reference information. Each bridge was then initially, and thoroughly, visually inspected and hammer sounded as accessibility allowed. Areas of discoloration or exhibiting obvious signs of decay or damage were documented in the notes, and marked for further investigation using NDE tools including a moisture meter, stress wave timer and resistograph Areas highlighted for further investigation were first tested for their moisture content and then an investigation of the area/member was conducted with the stress wave timer. Those areas/members found to consist of critical amounts of damage and/or decay with the stress wave timer were then further investigated with the resistograph to provide detailed information regarding the extent of the deterioration.

4. Iowa Bridge Inspection Case Studies

This section briefly describes the inspection of one bridge in each of the three clusters in Iowa, namely the Bremer 2 Bridge, Blackhawk 5 Bridge, and the Clarke 3 Bridge.

4.1 Cluster 1 – Bremer 2 Bridge

As mentioned previously, the timber bridges inspected in Bremer County were all single span timber girder bridges, constructed in the mid 1990's. The Bremer 2 Bridge, hereafter referred to as Bremer 2, was located on secondary gravel road (160th St.) approximately 9.7 km (6 mi.) northwest of Waverly in Bremer County and provides access over a drainage ditch. The bridge is oriented east-west, and is approximately 1.2 km (0.75 mi.) west of Hwy 27. Bremer 2 is 6.4 m (21 ft.) from center-center of bearing and approximately 7.3 m (24 ft.) wide. The superstructure consists of 25 Douglas-fir timber girders which are 102 mm (4 in.) x 406 mm (16 in.) and Douglas-fir deck planks measuring 76 mm (3 in.) x 305 mm (12 in.), all of which were treated with creosote.

4.1.1 Visual Inspection Findings

Bremer 2 is situated in a shallow sag curve on 160th St. and has a gravel wearing surface, although there were small signs of asphalt on the curbs. The deck planks were found to be in good condition, all seated well on the girders, and had gaps between adjacent planks of approximately 3 mm (0.125 in.) to 13 mm (0.5 in.). The guardrails were constructed of untreated dimension lumber which had been painted and were connected to the bridge by simply anchoring the rail posts on top of deck planks that were cantilevered off the edge of the bridge, see Fig. 8. This guardrail detail is not vehicle-impact sufficient and the members are showing sign of deterioration.

Fig. 8 Bremer 2 guardrail detail

From below, Bremer 2 was generally in pretty good condition. The girders at the end-of-bridge (EOB) side were found to have slightly higher moisture content readings (14-15% vs 12-13%) towards the north side of the bridge. On the beginning-of-bridge (BOB) side of the bridge there were areas on the timber abutment cap that showed signs of moisture as well as piles of debris between girder ends. This indicates there may be gaps between the backwall and the bridge deck allowing debris and runoff from the approaches to fall through and collect on the top of the abutment cap. The abutment cap was originally covered with felt or tar paper, however over time this protective layer has become ripped, and is missing in various locations.

Bremer 2, like all the other Bremer bridges inspected, also had timber block diaphragms located at midspan between all girders. In addition, at midspan were steel tension rods (one above and below the girders) that ran the full width of the bridge. See Fig. 9 for photos of the timber diaphrams and steel tension rod details, respectively. Both the timber diaphragms and steel tension rods were in satisfactory condition on Bremer 2.

From a purely visual standpoint, aside from areas that appeared to have minor moisture problems, the only other noted area of concern was the tension side of girders G12, G13 and G14 which all had significant number of knots.

a. Exterior tension rod connection *b. Tension rod between girder and deck*

Fig. 9 Steel tension rod on Bremer 2

4.1.2 NDE Findings

Hammer sounding and moisture content readings did not turn up any areas of significant concern that warranted further investigation with the stress wave timer or the resistance micro-drill. However several readings from both pieces of equipment were taken. Stress wave readings from girder G19 were approximately 58-60 micro-seconds, typical for sound timbers.

4.2 Cluster 2 – Blackhawk 5 Bridge

The timber bridges inspected in Blackhawk County were all single span timber girder bridges just like in Bremer County. However, these bridges were constructed in the early to mid 1980’s. The Blackhawk 5 Bridge, hereafter referred to as Blackhawk 5, was located on Tama Rd., a secondary gravel road approximately 8 km (5 mi.) east of Reinbeck in Blackhawk County and provides access over a drainage ditch. The bridge is oriented north-south, and is approximately 0.5 km (0.33 mi.) east of Hicks Rd. Blackhawk 5 is 5.8 m (19 ft.) from center-center of bearing and approximately 7.3 m (24 ft.) wide. The superstructure consists of 28 Douglas-fir timber girders which are 89 mm (3.5in.) x 406 mm (16 in.) and Douglas-fir deck planks measuring 76 mm (3 in.) x 305 mm (12 in.), all of which were treated with creosote.

4.2.1 Visual Inspection Findings

Blackhawk 5 has a gravel wearing surface and steel guardrails composed of I-beam posts and thrie beam rails. Each rail post was connected to the bridge via a steel plate that sat on top of the first three girders under the deck panels along with bolts through the exterior girder, see Fig. 10. In addition, attached to the bottom of the guardrail posts were steel channel sections, flanges pointing down that extended the full width of the bridge from rail post to rail post. The channel was nailed to the bottom of all girders to provide lateral support for the girders. The deck planks were found to be in good condition, all seated well on the girders, and had gaps between adjacent planks of approximately 3 mm (0.125 in.) to 13 mm (0.5 in.).

Fig. 10 Bremer 2 guardrail detail

From below, Blackhawk 5 was generally in pretty good condition. Noteworthy items include: some girders were found to have settled under load approximately 3 to 6 mm (0.125 to 0.25 in.) at the EOB; shimming was present at EOB between a couple abutment piles and the abutment cap; G19 had a plywood shim placed between it and the deck planks over its entire length as well as section loss due to a large splinter at midspan that was approximately 3-3.4 m (10-11ft.) in length. Girder G25 had the most significant deterioration. Hammer sounding, in addition to the ease with which the moisture meter pins could be inserted into the member, quickly identified a problem area that began at approximately 0.7 m (2 ft.) from BOB and extended to just past midspan. This area was investigated extensively with the stress wave timer and resistograph, the results of which are summarized below.

4.2.2 NDE Findings

Stress wave and resistograph readings were conducted at numerous location on girder G25 of the Blackhawk 5 Bridge. A sample resistograph plot is presented in Figs. 11. The stress wave readings along the member, along with comparison of resistograph readings helped identify and bound the location of the deterioration in girder G25. Areas of the plot that flatline to zero relative resistance (y-axis) levels are indicative of advanced decay.

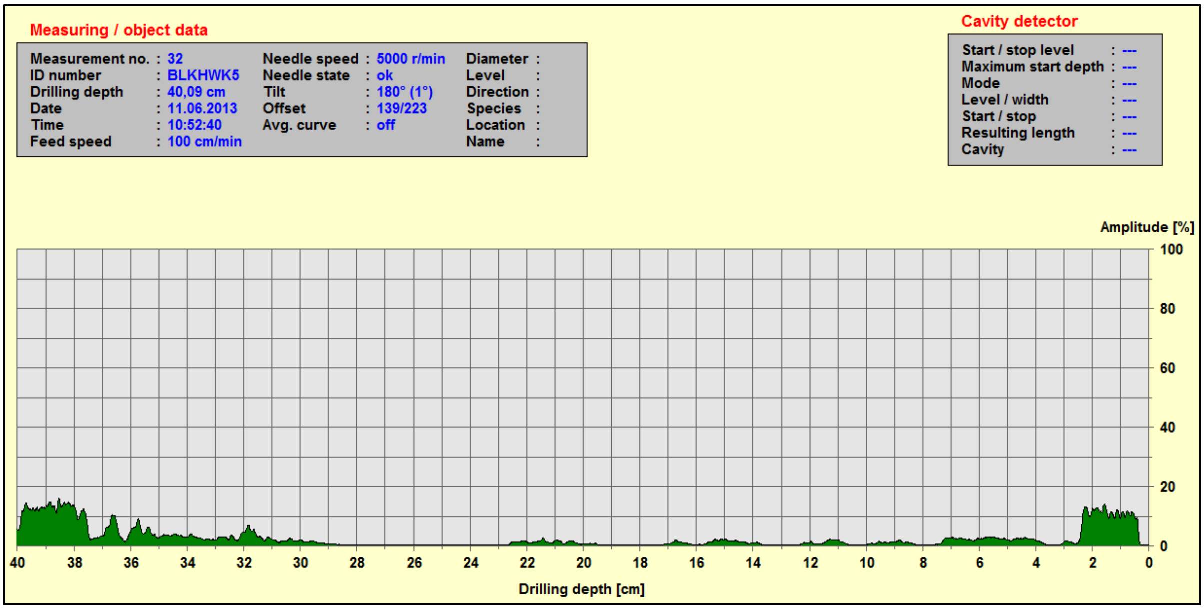

Fig. 11 Resistograph plot from girder G25, location 32, of Blackhawk 5

4.3 Cluster 3 – Clarke 3 Bridge

The timber bridges inspected in Clarke County were all single span timber deck bridges and were constructed in the early 1980's. The Clarke 3 Bridge, hereafter referred to as Clarke 3, was located on 250th Ave., a secondary gravel road approximately 4.8 km (3 mi.) northeast of Osceola in Clarke County and provides access over Otter Creek. The bridge is oriented north-south, and is approximately 1.6 km (1 mi.) south of Hwy 69. Clarke 3 is 9.5 m (31 ft.) from center-center of bearing and approximately 9.1 m (30 ft.) wide. The superstructure consists of nail laminated timber deck panels made up of Douglas-fir timbers each measuring 102 mm (4 in.) x 356 mm (14 in.). The nail laminated deck panels are then connected to each other with a lap joint and galvanized screws in predrilled holes. The bridge consisted of timber curbs with scuppers and timber guardrails, and all of the deck, rail and curb timbers were treated with creosote. Located at midspan of the bridge was a transverse stiffner beam that measured 152 mm (6 in.) x 305 mm (12 in.) and was attached to the deck with thru bolts.

4.3.1 Visual Inspection Findings

Clarke 3 has a gravel wearing surface that due to grading has all the scuppers partially to completely blocked. The most obvious signs of damage were at locations of physical connections, such as the guardrail post connections (see Fig. 12), and the longitudinal joint between deck panel sections where the lag screws have begun to push through the bottom of the deck and split the bottom of the member (see Fig. 13).

Fig. 12 Damage at connection detail between guardrail post and deck, Clarke 3

Fig. 13 Damage at longitudinal deck panel connection, Clarke 3

Other minor issues discovered in the visual inspection were that the EOB abutment cap was slightly rotated away from midspan and had slid back on the pile bearings slightly; in addition, the EOB abutment cap had checking and splitting on its interior face. Lastly, the transverse stiffener beam has signs of splitting/crushing at two of the interior thru bolt connection locations, but they were not significant at the time of this inspection.

4.3.2 NDE Findings

Overall moisture content readings were approximately 16-19% for both abutment caps, and the majority of the deck was in the range of 19-23%. These higher moisture contents in the deck are likely due to the fact that the gravel wearing surface is placed directly on top of the timber deck without any other separation or barrier.

Stress wave readings and resistograph readings at random locations revealed no areas of concern even around the areas were the deck was damaged/deteriorated due to the panel connection detail.

5. Challenges

For the three clusters of bridges in Iowa selected for inspection, very few challenges presented themselves. This is largely attributed to the research team conducting a thorough reconnaissance of potential bridge candidates prior to scheduling and conducting any inspections. This allowed for several candidate bridges, which had serious access issues, to be replaced with other bridges in the inventory which still met the needs of the project but provided better, and safer, access for the inspections.

Weather during the week most of the inspections were conducted was very cooperative and created no issues. It should be noted that only weeks prior to the time of the inspections, heavy spring rains had filled most of the streams, valleys and drainage areas that the subject bridges provide access over. Had the inspections been attempted 1-3 weeks earlier, access under most of the bridges would not have been possible due to high water.

No challenges in terms of unexpected wildlife presented themselves, aside from the one or two racoons found hiding between girder ends on an abutment cap, as well as the unavoidable mosquitos, ticks and barn swallows. However, preparedness in this regard (expect the unexpected) should not be overlooked.

6. Summary

In summary, the timber girder bridges in Bremer and Blackhawk Counties were typically rated between 6-7 (NBI Condition Rating) for the overall structural condition rating and, with the exception of two girders out of the five bridges inspected, all the bridges were found in good condition. The longitudinal timber deck bridges inspected in Clarke County were typically a 5-6 overall structural condition rating with most of the problem areas focused on the longitudinal nail-laminated panel joints and the abutments.

Initial visual inspection of the bridge components coupled with hammer sounding and moisture content readings provided adequate input on suspect areas of decay/deterioration for further investigation with the NDE tools (stress wave timer and resistance drill). Furthermore, the simplicity and output of direct, useful information from both pieces of equipment allows the inspector to quickly and accurately assess and document the location, extent, and bounds of any decayed/deteriorated areas.

7. Acknowledgements

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