Recent Research on Railroad Timber Bridges and Their Components

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Abstract:
An overview of some of the research related to the railroad timber bridges and their components undertaken over the past few decades is presented. This overview involves the surveys and workshops that were held to determine the research needs and the publications that described the status of research in progress, the field tests on bridges, laboratory tests on bridge components, the analytical work, and miscellaneous other pertinent research work.

The paper concludes that although field testing of bridges has provided a greater understanding of their behavior under train loading, further evaluation is desirable for more closely determining the actual forces carried by the individual components. The allowable longitudinal shear stresses given in the American Railway Engineering and Maintenance of Way Association (AREMA) Manual for Railway Engineering Chapter 7 could to be reviewed in light of the results of the full-scale tests on timber bridge ties and timber bridge stringers. Field tests have demonstrated that the methods of strengthening of timber bridges currently employed work to varying degree of effectiveness. Specially-engineered wood products offer promise for upgrading existing timber bridges because of their higher strength and other qualities. Regular inspection and proper evaluation followed by timely and adequate maintenance program could extend the useful service life of many existing railroad timber bridges for several years. The paper also concludes that the use of NDE techniques for determining the strength properties and decay in wood should be further investigated.
INTRODUCTION

Timber bridges, or trestles as they are often called, have existed since the beginning of the railroads in North America. They have been faster and more economic to construct for relatively short spans (Exhibit 1). Because of maintenance economics and limitation on span lengths, many have been replaced with steel or concrete structures. Nevertheless, there are still a large number of trestles in service today forming a significant part (approximately 29 percent) of the railroad bridge inventory. As the timber bridges age and are subject to ever-increasing axle loads, railroads want to assure their continuing safe performance under traffic. The outcome of the past research is being re-examined and new areas of research are being explored, and various methods of economically maintaining and strengthening are being re-evaluated in order to find ways to extend their service life.

Wipf et al. (1995) conducted a literature review on testing of timber railway bridges in a report funded by the Association of American Railroads (AAR). This was primarily an extension of the same effort. The Wipf report outlined the field and laboratory testing performed and it also cited various surveys conducted to establish research needs, status of research including those on that highway bridges applicable to railroad bridges, theoretical work, and other pertinent miscellaneous studies.

OBJECTIVES

The primary objective of this paper is to present a brief overview of some of the railroad timber bridge research performed during the past few decades and to highlight the salient findings of this research. The secondary objective is to cite the research needs established through various publications, surveys, and workshops, and to describe the areas of research previously identified that are either underway or remain in need of research.

This paper is a summary of a report which is divided into the following five sections:

- Surveys, Workshops, and Publications Determining Research Needs and Describing Research Status
• Field Tests on Bridges
• Laboratory Tests on Bridge Timber Components
• Analytical Work
• Miscellaneous Research Work

SURVEYS, WORKSHOPS, AND PUBLICATIONS
DESCRIPTING RESEARCH STATUS AND DETERMINING RESEARCH NEEDS

Wipf et al. (1997), Foutch (1989), Foutch et al. (1994), and Jones (1997) cited the results of the literature reviews, surveys, and workshops to determine research needs. Wipf listed 22 research projects out of 118 potential projects ranging from materials, preservatives, construction, and maintenance to economics. Foutch found that the two highest rated short-term projects involved the development of methods for determining the ultimate shear, bearing, and bending strength for both new and existing timber bridges. Other short-term projects that received moderate support were the study of load path for existing bridges through field testing and the development of nondestructive techniques for evaluation of strength and remaining life of existing bridges. Jones summarized the previous research in fatigue of timber stringers by Lewis, the AAR and Tsai and Ansell.

Other research

A brief description was given on the status of several research projects in progress at different times as reported by Magee (1967), Freas (1967), Bohannan (1968), Oliva (1990), GangaRao (1990), Crews (1994), and Ritter et al. (1998, 1994). Some of the research projects pertinent to timber bridges are stated:

• Stresses in components of timber trestles
• Different softwood and hardwood species for bridge components
• Glued laminated and stressed laminated construction
• Preservative treatments of timber
• Nondestructive evaluation (NDE) techniques for timber
FIELD TESTS ON BRIDGES

Nine railroad timber bridges were tested under train loading and at varying train speeds to study their dynamic performance. Exhibit 2 is a photograph of timber trestle under dynamic testing. The University of Manitoba; as reported by Uppal, et al. (1990) and Graham (1993), tested three of the bridges. Iowa State University carried out five tests on three more of the bridges, as reported by Wipf et al. (1993, 1997). Colorado State University performed tests on the remaining three bridges as reported by Gutkowski et al. (1999) and Robinson et al. (1998). All but the first three tests were performed for the Association of American Railroads (AAR). The following general inferences were drawn from the findings of some of the tests:

- The load deflection behavior of the bridge span was fairly linear, in contrast to the nonlinear behavior of bridge approaches and that of the normal track section.
- The ballast deck span was comparatively stiffer than the similar open-deck one (Exhibit 3). The bridge spans were stiffer than the approaches, which in turn were stiffer than the track sections. The vertical loads measured by shear circuits at crawl speeds compared closely to those obtained from wayside scales.
- Typical load and displacement versus time plots for the open deck timber bridge in Exhibit 4 are shown in Exhibits 5 and 6, respectively.
- For both the open deck and the ballast deck spans, the dynamic load factors and the dynamic displacement factors increased with increase in train speed.
- The maximum dynamic displacement factors (i.e., the ratio of dynamic to static displacements) for the open deck was found to be 1.19 and that for the ballast deck was found to be 1.57.
- The differences in deflections of spaced stringers versus packed stringers of a chord were small.
- The individual stringers in a chord did not behave as a unit. This situation appears to increase with lowering of bridge condition. However, stringer deflections were successively more consistent for glued laminated stringers chords and ballast deck spans.
• There was an insignificant amount of continuity over deflections between the stringers in two adjacent open deck spans.

• The dynamic performance of a timber bridge depends very much on the condition of its material, the condition of fasteners, and the bearing of the its components.

• The methods of strengthening that were tested in the field -- the use of helper stringers on the outside of the existing chords and between the existing chords (Ritter et al., 1994), replacement of chord made out of the solid sawn stringers with those made out of the glued laminated stringers (Ritter et al., 1995), and the conversion of an open deck to a ballast deck -- all work to increasing degrees of effectiveness. The choice of the method depends on many factors including the existing condition, future life expectancy, and cost of the strengthening (Exhibit 7 a and b).

• Modulus of elasticity (MOE) values for the bridge spans determined by ultrasonic techniques fall within the range of those established by the conventional methods.

• The structural modeling is required to predict response. However, this modeling is complex and expensive because of the variables involved.

• Exhibit 8 is a photograph of a stress laminated deck test bridge. From the tests on the stress laminated deck slab span, the following general additional inference was drawn:
  − The measured deflections at midspan showed a decrease in deflection with an increase of the test train speed.
  − Exhibits 9 and 10 show longitudinal and transverse deflections for different train speed. The deflections measured in the transverse direction indicated that the stress laminated deck slab behaved like an orthotropic plate with loads being resisted both in the longitudinal and the transverse directions.

**Field Monitoring and Testing**

Field monitoring and testing on about two dozen highway bridges have been reported by GangaRao et al. (1991) of West Virginia University, Ritter et al. (1995, 1996), Wacker et al. (1984, 1992, 1995, 1996),
Hislop et al. (1996), Kainz (1996), Hilbrich (1996, 1997), and McCutcheon (1992) of the United States Department of Agriculture (USDA) Forest Products Laboratory. As illustrated in Exhibit 11, the bridges were either stress laminated or a combination of stress laminated and glued laminated construction. Different species of softwood and hardwood were used, treated with different preservatives, and made of different cross sections such as slab, tee, and box sections. The bridges were monitored over periods of two to five years. All were performing well with minor or no serviceability deficiencies, except three bridges that had developed slight sags due to the vertical creep. Exhibits 12 and 13 show displacement profiles at various longitudinal and transverse sections, respectively, with an applied displacement of 1 inch.

Exhibit 14 illustrates three configurations for stressed-timber decks: basic, box section, and T-section. Tests by GangaRao also indicated the following:

- The measured live load deflections and strains were consistently less than those that were calculated in the design process.
- The bar force levels remained above or near 50 percent of the initial jacking level, which means that the ability of the stressing bars to maintain compressive force on bars is satisfactory.
- The loss of camber was evident on all monitored bridges and was substantially larger than anticipated.
- The environment had little detrimental effect on the bridges tested.

LABORATORY TESTS ON BRIDGE TIMBER COMPONENTS

Bridge Ties

Soudhki et al. (1991) and Madsen (1995) carried out static and dynamic tests on Douglas fir bridge ties.

Soudhki et al.

The purpose of the tests conducted by Soudhki was to determine the axle load distribution and longitudinal shear strength using large size shear specimens and fatigue life of ties. The test setup was
similar to tie supports in service (see Exhibit 15). Some of the inferences drawn from the tests were as follows:

- The axle load distribution per tie was at least 25 percent and 30 percent of the axle load for bridge ties with support girders spaced at 8 feet and 7 feet, respectively. A 14-inch on-center spacing of ties produced a stiffer deck where the axle load distribution is more spread than in a 16-inch tie spacing. Further, the use of tie pads resulted in a concentration of the axle load distribution. Exhibit 16 shows the setup for bridge tie load distribution tests and Exhibit 17 plots the typical axle load distribution data per tie for beams at 8 feet and ties at 14 inches on-center with no tie pad.

- The ultimate shear ranged from a minimum of 650 psi to 930 psi. The length of shear region did not effect the ultimate shear stress. The failure of the shear specimens was by radial and tangential splitting along the shear region. See Exhibits 18 and 19 for shear test setup and typical load for shear strain curves.

- Eight bridge ties were dynamically tested in four-point loading. The total load varied from 30 kips (125 psi) to 95 kips (396 psi) and there was no failure at 5 million cycles to failure at 675 cycles, respectively. Exhibit 20 depicts timber bridge ties applied load versus number of cycle to failure.
Madsen

The objective of the tests conducted by Madsen was to establish realistic estimate of bridge tie actual shear strength. The test setup is shown in Exhibit 21. A total of 400 ties (200 new and 200 removed from a bridge after more than 30 years of service) were tested with different amounts of overhang. Some of the findings of these tests were as follows:

- The shear capacity of the bridge ties was higher than the bending capacity when tested with overhangs, but about equal when tested in flush end condition. The overhanging ends of ties almost doubled the shear capacity.
- When the ties were dapped, they lost 24 percent of their original bending capacity but did not cause a similar loss in the shear capacity.
- The difference in bending capacity of treated and untreated ties was 7 percent. This is not explicitly recognized in the current design codes.
- The shear capacity of timber was much greater than shown in the present building codes. The allowable shear stress could safely be 200 psi. Exhibit 22 illustrates the timber bridge tie shear strength in the flush condition and Exhibit 23 shows bending strength.

Timber Stringers

Chow

Chow et al. (1997) conducted static tests of old stringers, the survivors of a much larger population of in-service stringers. The objectives of the Chow tests were to conduct ultimate static bending strength tests on full-size railroad bridge stringers and to determine if it is possible to justify the increase in the allowable stress through these tests. The test setup is shown in Exhibit 24. The results are shown in Exhibits 25 and 26. An average maximum shear stress value and the average maximum bending stress value at failure were found to be 270 psi and 300 psi for Douglas fir, respectively; and 3,500 psi and 4,000 psi for southern pine, respectively. The mode of failure of all lengths of stringers was in shear or in a combination of shear and tension.
Fry et al.

Fry et al. (1999) reported both static and dynamic tests on new stringers of timber bridges. The objective of the tests conducted by Fry were to develop stress range versus number of cycle of loading (S-N) curves for timber similar to those used for steel to determine the remaining fatigue life of beams. This ongoing program involves tests on southern pine, Douglas fir, and glued laminated stringers. The test setup is shown in Exhibit 27. To date, static tests on southern pine are complete and dynamic tests on southern pine are complete. The specimens tested so far failed in shear. The static tests resulted in an average maximum shear stress of 355 psi. Preliminary indications from the dynamic tests are that a longitudinal shear stress value of 100 psi or more for design could be safely used for yellow pine stringers. Exhibit 28 illustrates timber stringer shear stress versus number of cycles.

Pellerin and Peterson et al.

Pellerin (1995) and Peterson et al. (1999) have successfully used in-laboratory and in-place NDE techniques for determining the strength properties and deterioration in wood members.

Tsai and Ansell

Tsai and Ansell (1997) indicated that the failure life is largely species-independent when normalized by static strength. Their report also indicates that moisture has detrimental effect on fatigue life not only in reducing the fatigue life but also in accelerating the fatigue damage process.

Rammer and Lebow

Investigations by Rammer and Lebow (1997) indicated that the shear strength of green, solid sawn Douglas fir beams is not constant but varies with the size of beam. Larger beams have lower shear strength.

Triantafillou

Triantafillou’s (1991) study showed that fiber-reinforced plastic sheets bonded to wood beams could substantially increase its shear capacity and that this cost- and work-efficient reinforcement could be
applied with minor influence on the aesthetics of wood. Exhibit 29 shows test details of wood beams reinforced with carbon fiber plastics (CFP). Exhibit 30 shows typical load versus midspan deflection diagrams for wood beams reinforced with fiber reinforced plastic (FRP) in shear.

Johns and Madsen

Johns and Madsen’s (1982) extensive work on the duration of load effect on lumber inferred that the load duration phenomenon has proved to involve a definite stress effect, with differing behavior for different levels of applied stress. It was suggested that a 2-year loading time be used as the basis for published allowable stresses instead of the 10-year period presently used.

Gutkowski et al.

Laboratory load tests were conducted by Gutkowski et al. on full-size specimens replicating the main elements of three-, two-, and single-span bridge chords. Initial results, shown in Exhibit 31, indicated modest difference in the midspan displacement between deck case; thus, lack of continuity at supports. The models used did not closely predict the measured values mainly because of the support movements.

Other Research

Tests conducted especially on engineered wood products by various researchers indicate that much higher allowable design stresses could be used for these products as opposed to the solid sawn timber. These products also indicated far less variability in strength properties, and offer greater choices of forms and span lengths and better preservative treatment. Though the use of the especially engineered wood products thus far has been limited in railroad bridges, they have performed well in varying climatic conditions. Exhibit 32 is a comparison of allowable shear stresses for several species of wood.

ANALYTICAL WORK

Uppal et al.

Uppal et al. used a multi-degree of freedom vehicle-bridge model for predicting the load at wheel-rail interfaces, vertical displacements, and accelerations at midpoints of a ballast deck and open deck timber bridge span (see Exhibits 33 and 34). Despite its limitations, this model has offered a means of comparison with the experimental values and of carrying parametric studies. Exhibit 35 shows a comparison between measured and predicted displacement versus time plots. The model could be enhanced to include the stresses in members and several other features.

Rammer and Lebow

Rammer and Lebow developed a mathematical relationship between beam shear and ASTM shear block strength, including a stress concentration factor for the re-entrant corners of shear block.

Triantafillou

Triantafillou's analytical work showed a level of effectiveness for fiber reinforced plastic (FRP) reinforcement. The report also discussed how FRP reinforcement was maximized when fibers were placed in the longitudinal direction and the height of externally bonded sheets was just a little higher than a limiting value, beyond which FRP precedes wood failure.

Oliva et al.

Oliva et al.(1990) used a commercial finite element computer program with orthotropic plate modeling capabilities that accurately predicted the behavior of stress-laminated bridge decks. The two analytical techniques used were capable of providing satisfactory simulation of actual stressed deck behavior as measured experimentally. Exhibit 36 provides FPL deck and pre-stressing details.

Johns and Madsen

Johns and Madsen treated the duration of load effect as a visco-elastic, limited ductility fracture mechanics model involving two creep parameters and one strength parameter. They generated a family of
curves for different levels of applied stress versus lifetime as a function of percentage of short-term strength applied. Exhibit 37 shows the numerical results for constant stress.

**MISCELLANEOUS WORK**

**Laine et al.**

A study by Laine et al. (1996) showed that the plate compression fatigue was neither a problem, nor a major contributing factor in the deterioration of creosote-treated red oak cross ties under 33-kip or 39-kip wheel loading.

**Jimenez et al.**

Jimenez et al. (1999) reported on gage widening and degradation of different types of ties (e.g., hardwood and softwood ties, reconstitutes ties, glued laminated ties, parallel strand laminated ties) with different rail anchoring arrangements under service tests on a loop at the Facility for Accelerated Service Testing (FAST) located at the Transportation Technology Center near Pueblo, Colorado. Exhibit 38 provides the calculated gage widening rate in Section 7, 5-degree curve with 4 inches superelevation at FAST.

**Uppal and Otter, Muchmore, and Verna**

Uppal and Otter (1998) gave an outline of methodologies for strengthening and extending life of existing railroad bridges and Uppal (1990) illustrated the use of laminated timber (i.e., glued laminated and stress laminated timber) in railroad bridges. Muchmore (1983) described the properties of treated wood as a structural material and stated that wood is an economical and practical structural material for many short span bridges when properly treated to prevent early decay deterioration. Verna et al. (1990) described the benefits and detriments of timber as a material for bridge construction.

**Other Sources**

The AREMA *Manual for Railway Engineering*, Chapter 7, “Timber Structures” provides for design and construction of railroad timber bridges or trestles. The following materials provide excellent guidelines for design, construction, and maintenance of wood bridges:
CONCLUSIONS

During the past few decades, a fair amount of research on timber has been carried out. Exhibit 39 is a photograph of a timber railroad bridge. Work that is considered to be more pertinent to railroad bridges has been discussed in this report. Based on this brief overview of the literature, the following concluding remarks are made:

- Although the field testing of bridges has provided a better understanding of their behavior under train loading, still more tests are desirable for more closely determining the actual forces carried by the individual components.

- The allowable longitudinal shear stress values given in the AREMA Manual, Chapter 7 could be reviewed in light of the results of full-scale tests on timber bridge ties and timber bridge stringers.

- Field tests have demonstrated that methods of strengthening of timber bridges work to varying degrees of effectiveness. The choice of the method to be employed depends on many factors including condition, future life expectancy, and cost.

- The conversion of an open deck to a ballast deck has shown advantages.

- The use of the specially-engineered products of wood such as glued laminated, parallel strand laminated and stressed laminated timbers offer promise in upgrading and life extension of the existing railroad timber bridges. They possess higher allowable design stresses as opposed to the solid sawn timber of the same species, can have far less variability in strength properties, and can offer greater choices of forms and span lengths, and better preservative treatment.
• With regular inspection and proper evaluation followed by timely and adequate maintenance program, the useful service life of many existing railroad timber bridges can be extended by several years.

• Repairing/reinforcing wood members using fiber-reinforced plastic should be further investigated in view of the need for prolonging the life of the existing timber bridges.

• Use of NDE techniques for determining the strength properties and for determining decay in wood may be beneficial. This may offer an effective way of finding internal defects in wood without using of test drilling.
Exhibit 1. A Timber Trestle under a Curved Track
Exhibit 2. Timber Trestle under Dynamic Testing

Exhibit 3. Relative Stiffness of Timber Bridges Spans, Bridge Approach and Track
Exhibit 4. Open Deck Timber Bridge

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Exhibit 26. Percentage Exceeding Ultimate Shear Stresses
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Exhibit 30. Typical Load Versus Midspan Deflection Diagrams for Wood Beams Reinforced with FRP in Shear
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Exhibit 32. Comparison of Allowable Shear Stresses

<table>
<thead>
<tr>
<th>Species of Timber</th>
<th>Shear parallel to grains (psi)</th>
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<tr>
<td>Softwood</td>
<td>60-85</td>
</tr>
<tr>
<td>Hardwood</td>
<td>80-145</td>
</tr>
<tr>
<td>Glue-laminated (Softwood)</td>
<td>90-165</td>
</tr>
<tr>
<td>Parallel-strained Laminated (softwood)</td>
<td>175-290</td>
</tr>
</tbody>
</table>
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Deck Span was 24 ft, and the Transverse Stressing was at 50 lb/in². The Comparison Shown is for a Point Load at Center at Midspan. (ML89 5824)

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(1psi = 6.89 kPa)
Exhibit 38. Calculated Gage Widening Rate in Section 7, 5-degree, 4-inch Superelevation Curve
Exhibit 39. Railroad Timber Bridge
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