Timber Bridges In The United States

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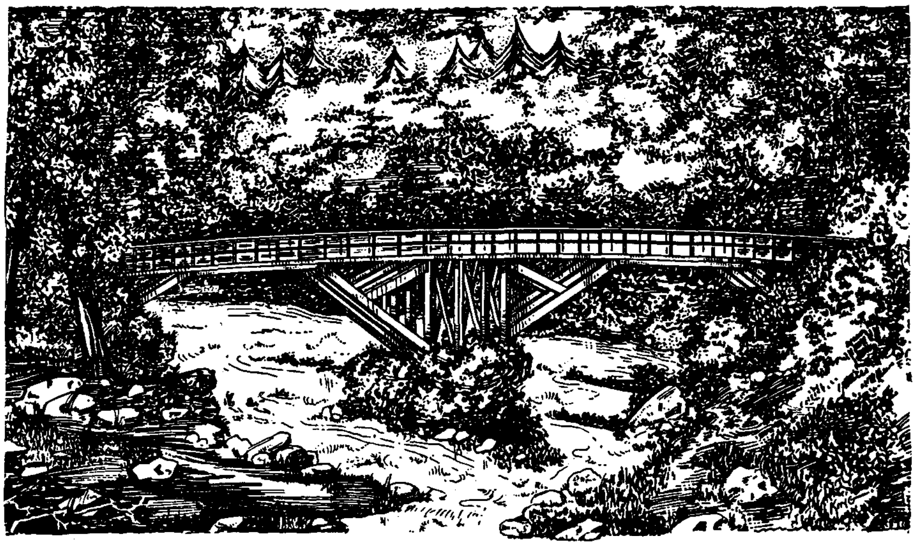
Introduction

Timber bridges represent approximately 7 percent of the 576,874 bridges listed in the National Bridge Inventory (NBI). In addition, another 7.3 percent of the bridges in NBI are timber decks supported by steel stringers and are, therefore, classified as steel bridges. Historically, timber was the primary material for bridges, but it was slowly replaced by iron, steel. and concrete in the late 19th and early 20th centuries. However, even with the development of steel and concrete bridges, timber bridges continued to be built on secondary and low-volume roads because much of the United States was heavily forested and wood was plentiful. [1]

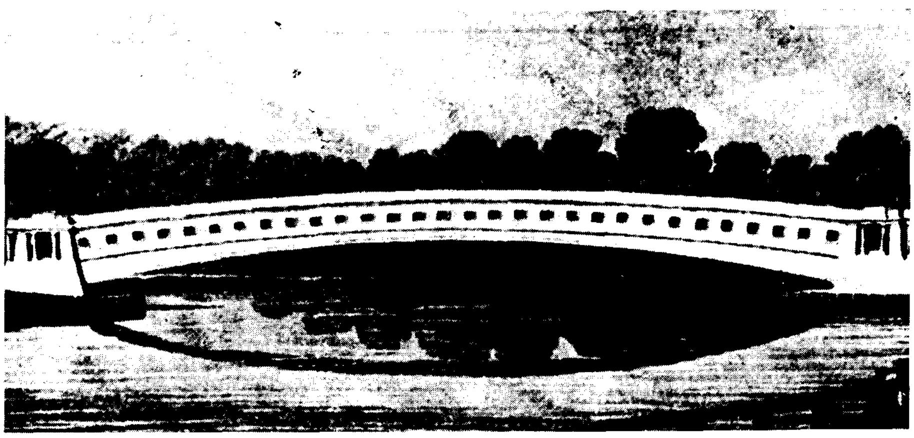
Thousands of timber bridges still exist today, and state and local authorities continue to build bridges out, of wood, as wood can be an attractive material for short-span structures. One focus of modern timber bridges is the use of previously rarely used species that are native to the particular region of the United States and generally yield smaller sizes and lower grades of lumber. Extensive research is under way at numerous universities through programs sponsored by the Federal Highway Administration (FHWA) and the U.S. Department of Agriculture (USDA&Forest Service to provide design values for the underused wood species and to develop more efficient designs, improved preservative treatments, and new types of incidental structures such as bridge rails and sound walls.

Wood is a desirable bridge construction material for several reasons. It is a renewable resource that is resistant to the effects of deicing agents and can sustain substantially higher loads over a short period of time. It is lightweight and easier to fabricate and construct, and it can be constructed in any type of weather without affecting the material.[2]

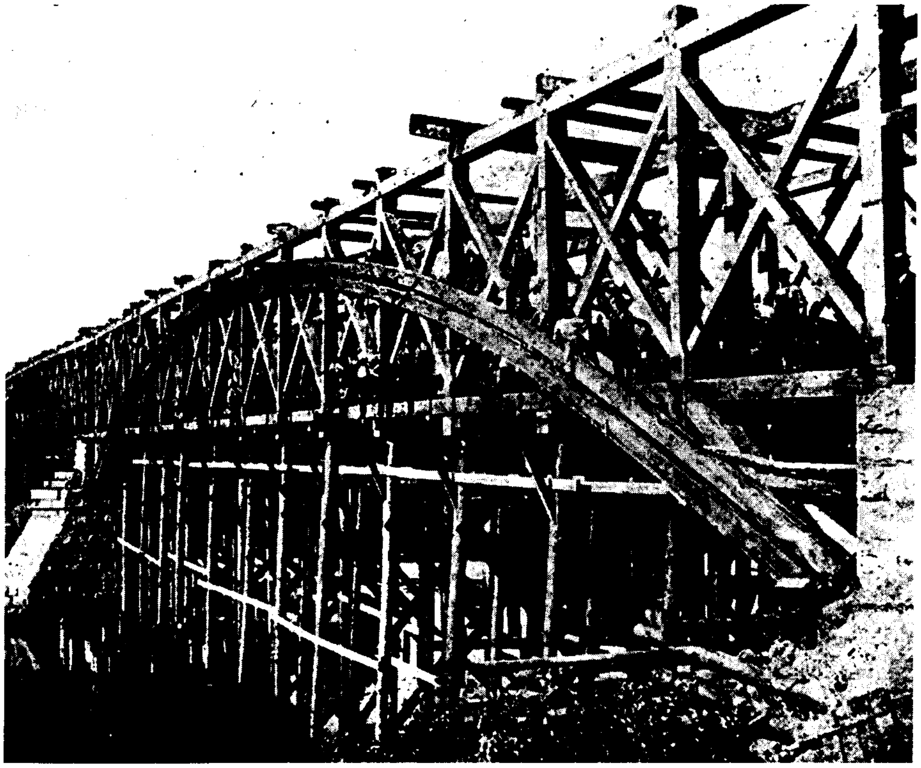
Wood is orthotropic, which means that its material properties vary in different directions. Strength is greatest in the direction parallel to the grain and is weakest perpen-



Enoch Hale's timber bridge over the Connecticut River (Bellows Falls, Vt.), 1785.



The "Colossus" over the Schuylkill River (Philadelphia, Pa.), 1812.



A Burr railroad bridge over the White River (White River Junction, Vt.), 1848.

dicular to the grain. The material properties of wood also vary between different species of wood. Design provisions and tabulated design values for different species and grades of lumber are given in the American Association of State Highway and Transportation Officials' *AASHTO Standard Specifications for Highway Bridges and the National Design Specification for Wood Construction* and its supplement.[3-4]

This article presents a historical perspective on the use of timber bridges, briefly describes the different types of timber bridges, and summarizes the national timber bridge demonstration and research programs.

Timber Bridges Through the 19th Century

Timber bridges have always been a part of the American landscape as the early American settlers used wood bridges to cross the many streams and rivers in the country. Many of those structures were considered remarkable feats of construction at the time, and many bridge builders were granted patents for their designs. The examples given in this section are adapted from "A History of the Development of Wooden Bridges," a paper by Robert Fletcher and J.P. Snow, published in the *Proceedings of the American Society of Civil Engineers* in 1934.[1]

The Great Bridge, built in 1660 across the Charles River, was 82 meters (m) long and was supported on 13 piers. Another bridge over the Charles River, built in 1685, was 458 m long on 75 piers. The first bridge over the Connecticut River was Enoch Hale's timber bridge, which was a two-span structure, 111 m long and supported at the center on a natural rock pier. Lewis Wernwag built the Colossus in 1812 over the Schuylkill River at Philadelphia, Pa. This bridge had a clear span of 104 m with a cross section composed of five parallel arched trusses, each with a rise of 6 m.

During the mid-19th century, Burr trusses became popular. Burr's Waterford Bridge over the Hudson River consisted of four spans, with clear spans ranging from 47 to 55 m. It lasted for 105 years without material strengthening, until it was destroyed by fire in 1909. Hundreds of highway bridges built more or less on the Burr principle were also built in the eastern, middle, and New England states. Deterioration usually was not a problem if the bridges were properly protected by roof and side coverings.

Also in the mid-1800s, Town lattice trusses were popular. Ithiel Town's lattice truss bridges were built to carry railroad traffic in areas of the country where timber was plentiful. They were also used extensively for highways in the valleys of the Connecticut and Merrimac Rivers in New Hampshire and Vermont. In 1900, at least 100 bridges of this type were on the Boston and Maine Railroad System.

William Howe was granted a

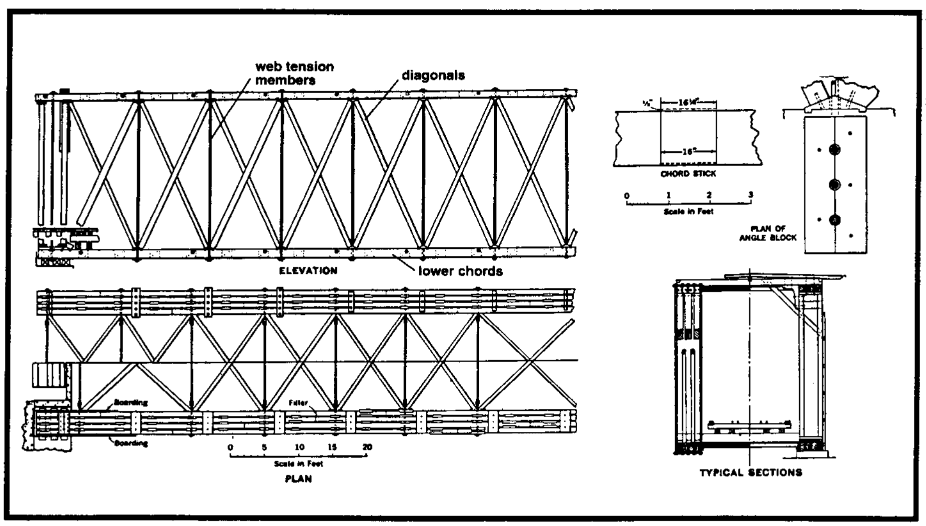


Figure 1 - Howe truss railroad bridge, 1889.

The Keystone Wye bridge, an arch bridge built with glulam beams (South Dakota), 1968.

patent in 1840 for the Howe truss bridge. which was a very popular design for many years. This bridge was constructed mostly of wood but used iron rods for web-tension members. In 1844, Thomas W. Pratt was granted a patent for the Pratt truss, which used iron rod diagonals and timber verticals. The development and use of iron in these bridges soon led to the use of iron lower chords and other components, and this was followed by the combination bridges consisting of iron diagonals and lower chords with timber used as compression members. In 1859, Howard Carroll built the first all-wrought-iron bridge for railroad use, beginning a slow decline in the use of timber bridges.

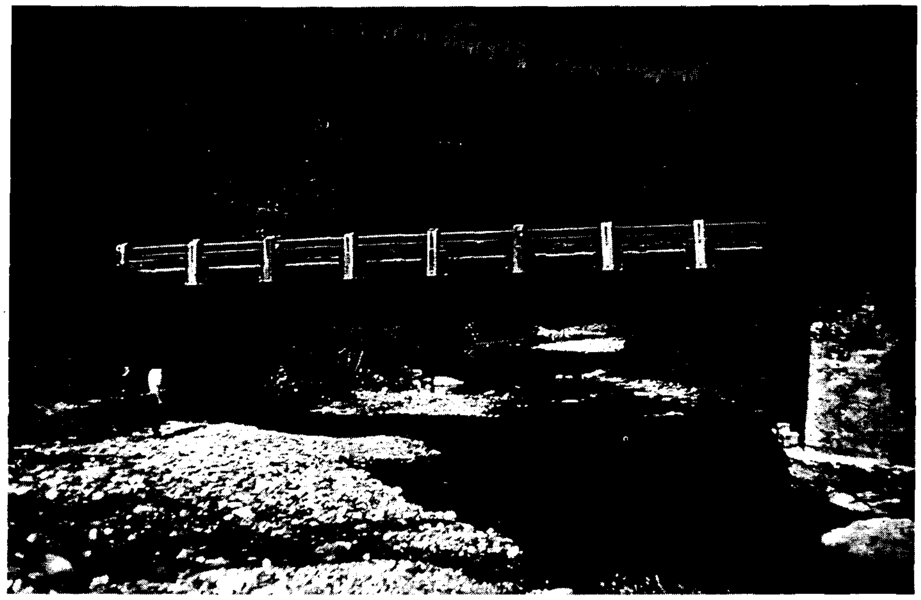
Early 20th Century Timber Highway Bridges

As the automobile came into existence and technology advanced, steel and concrete became the materials of choice for constructing highway bridges. However, timber bridges continued to be built on secondary and low-volume roads because much of the United States was still heavily forested and wood was plentiful. As late as 1930, there were between 450 and 500 covered timber bridges in use in the United States, and in 1932, the state of Ohio found it appropriate to build 93 timber highway bridges. With the development of better means of protecting wood from destructive elements, covered timber bridges were slowly replaced by other timber bridge types.

In addition to the covered bridges and trusses, several other types of timber bridges evolved to meet the requirements for secondary roads. One of the most common was the sawn lumber stringer bridge. These bridges are constructed of closely spaced lumber beams that are commonly 102 to 203 millimeters (mm) wide and 305 to 457 mm deep.[5] (An inch is slightly more than 25 mm. A foot is almost 305 mm.) Lateral support and alignment of the beams are provided by solid wood blocking or cross-bracing between the beams. These bridges are limited in span by the size and species of available lumber beams. Maximum clear spans averaged 6 m although spans up to I4 m were constructed in areas where large sawn lumber stringers were available.

One of the most popular types of timber deck from the 1920s to the mid-1950s was the nail-laminated lumber deck. This deck type was constructed of sawn lumber 50 mm thick and 102 to 305 mm deep. The wide dimension was vertical and nailed or spiked together to form a continuous surface. These decks were commonly used in a transverse orientation (with the boards perpendicular to the flow of traffic) on sawn lumber or steel stringers spaced 0.6 to 1.8 m apart.[5] They were also used in a longitudinal orientation (with the boards parallel to the flow of traffic) over transverse floor beams or in a longitudinal orientation as a deck-type structure designed to resist all the applied loads and deflections without additional supporting beams. Nail-laminated lumber deck bridges continue to be used on low-volume, unpaved roads because they are inexpensive and provide adequate service for these road types. They are generally not used on paved roads because, after years of service, the nails tend to loosen, causing the asphalt wearing surface to deteriorate.

Nail-laminated lumber decks have also been used in combination with concrete to construct composite slab decks. These bridges are constructed by using cast-in-place concrete on longitudinally oriented nail-laminated sawn lumber. The lumber is placed edgewise, parallel to traffic, with alternate planks raised 35 to 50 mm to form grooves in the base. Composite action between the timber and concrete – the timber and concrete acting as a unit to carry the load – is most commonly achieved through the use of triangular steel "shear developers" driven into the grooves. Composite slab decks were first built in 1932 and were used mostly during the 1930s and 1940s. They are not commonly used today.



A glulam girder bridge.

Modern Timber Highway Bridges

Although the use of wood as a bridge material declined through the early 20th century, interest in wood bridges has resulted in many technological advances that continue to evolve. Most notable have been the development and refinement of wood preservatives and the use of structural glued-laminated timber (glulam), stress-laminating, and structural composite lumber.

A stress-laminated glulam deck bridge over theTeal River (Wisconsin), 1989.

Preservatives

Because wood is a biological material, it is vulnerable to damage by fungi and insects. However, for biological deterioration to start, four elements must be present – food (wood), oxygen, moisture, and a favorable temperature. Much of the potential for biological deterioration can be prevented by proper preservative treatments. The preservative poisons the wood and eliminates the food source.

There are two broad classifications of wood preservatives: oil-type and waterborne. Oil-type preservatives, which include creosote, pentachlorophenol, and copper naphthenate, generally leave the wood with an oil-like surface that is not paintable. Waterborne preservatives, such as chromated copper arsenate (CCA), ammoniacal copper zinc arsenate (ACZA), and ammoniacal copper arsenate (ACA), are applied in water solutions that leave a paintable surface. Most timber bridges have historically been treated with the oil-type preservatives because they provide a moisture-resistant layer on the wood surface. Waterborne preservatives are most commonly used for pedestrian bridge components that are subject to human or animal contact, but they are becoming more popular for sawn lumber applications in new types of timber bridges.

When properly applied, all of the modern wood preservatives protect the wood from deterioration for many years. The effectiveness of treatment depends on an adequate penetration and retention of the chemical preservative. Specifications for preservative chemicals, penetration, retention, and treatment procedures are given in the *American Wood Preservers' Association (AWPA.) Book of Standards.*[6] For best performance, it is important that all fabrication, including drilling and cutting, be done before pressure treatment so that all exposed surfaces of the wood are protected. Premature deterioration of timber bridges can often be attributed to improper construction practices where the treated wood is cut and is not properly field treated with preservatives.

Creosote, pentachlorophenol, and inorganic arsenicals are classified as restricted-use pesticides by the Environmental Protection Agency. This classification means that the preservatives must be applied by a licensed applicator who is knowledgeable in proper application and in environmental and safety procedures. However, the treated wood itself is not restricted. It is a common misconception that treated wood is banned or restricted. Specific use and handling precautions are described in the Consumer Information Sheet available from the American Wood Preservers Institute.

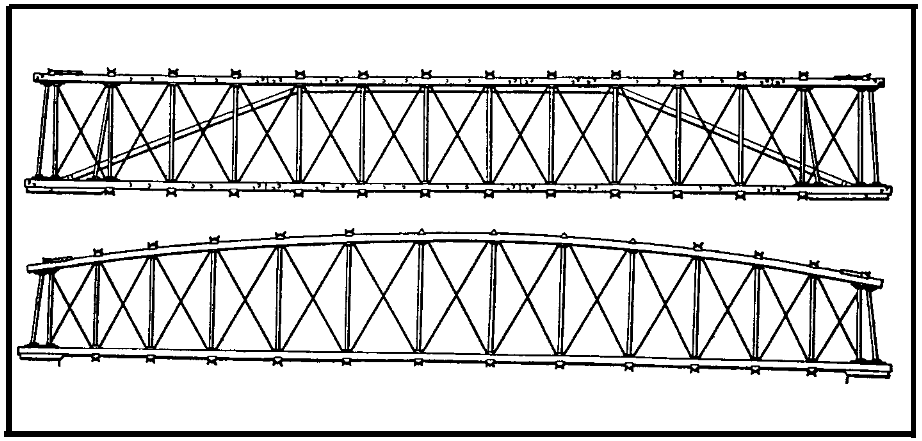


Figure 2 - Pratt truss, as patented in 1844.

Glued-Laminated Timber (Glulam) Bridges

Glulam is an engineered, stress-rated product. It consists of selected and prepared layers of lumber that are bonded on their wide faces with waterproof structural adhesive. Glulam has been used in the United States for indoor applications since 1935. The development of wet-use adhesives in the mid-1940s allowed its use in outdoor environments.[7] Although glulam can be manufactured from virtually any softwood or hardwood species, most of the glulam beams that have been used for the past 60 years have been from softwood species. Research has been ongoing at Pennsylvania State University, West Virginia University, and the Forest Service's Forest Products Laboratory (FPL) to develop glulam beams using hardwood and other underused species. Several hardwood glulam options have been developed. In July 1995, the first red maple glulam highway bridge was constructed in East Pennsboro Township, Pa.

The advantage of glulam for bending members is that the laminations can be placed selectively. This means that in a horizontally laminated beam, higher quality material can be placed at the top and bottom of the member where stress is the greatest. The laminating process also disperses the strength-reducing characteristics, such as knots, throughout a member. This results in reduced variability within a member and increased strength characteristics. Better dimensional stability can be obtained with glulam than with sawn lumber because glulam is manufactured using dry lumber. Furthermore, the size of a glulam beam is not limited to the size or shape of the available lumber and is generally only limited by transportation and/or restrictions imposed by a pressure treating facility.

The most common glulam bridges used today are girder bridges and longitudinal deck (or slab) bridges. Arch bridges can also be built effectively with glulam beams. The most visible of these is the Keystone Wye bridge built in 1968 in South Dakota. This is a three-hinged arch spanning 49 m with a total length of 88 m, including the approach spans.[8]

Girder Bridges

Glulam girder bridges consist of a series of transverse glulam deck panels supported on straight or slightly curved glulam girders. The glulam girders are manufactured from 35- or 38-mm-thick lumber laminations and are available in standard widths ranging from 76 to 362 mm. Because of the large size of glulam girders, glulam girder bridges require fewer beams and are capable of much longer clear spans than are conventional sawn lumber stringers. They are most commonly used for spans of 6 to 24 m but have been used for clear spans of more than 42 m.

The glulam deck panels typically span transversely across the full bridge width. The deck panels consist of vertically laminated lumber, usually 125 or 170 mm thick and 1.22 m wide. The panels are placed side-by-side, and the joints are sealed with a bituminous sealer to provide a watertight deck surface. Glulam deck panels of this type are also commonly used on steel stringers and are becoming increasingly popular for deck replacement on steel truss bridges. The panels are attached to the beams through the use of mechanical fasteners.

Longitudinal Glulam Decks

Glulam longitudinal deck bridges are constructed using a series of glulam panels placed side-by-side to form the deck width that spans the length of the bridge. The deck is designed to resist all applied loads and deflections without additional supporting members or beams; however, transverse distributor beams are attached with mechanical fasteners to the deck underside to assist in load distribution between the panels. The panels for glulam longitudinal deck bridges are typically 222 to 362 mm deep and 112 to 168 mm wide. This type of bridge is economical and practical for maximum clear spans up to approximately 11 m. Longer crossings are achieved with continuous multiple spans. The low profile of these bridges also makes them desirable when vertical clearance below the bridge is limited.

Stress-Laminated Bridges

Stress-laminated timber bridges are constructed by compressing timber components together with high-strength steel bars. The compression develops friction and load distribution between the components so that they act together as a large orthotropic plate. The concept of stress-laminating was first developed in Canada in the mid-1970s and was introduced into the United States in the mid-1980s. Stress-laminated bridges are attractive for several reasons. They can generally be designed using smaller sized, lower grade lumber. As with glulam, the stress-laminating disperses natural strength-reducing characteristics in the lumber so that variability is reduced and higher design values are possible. Currently, there are more than 300 stress-laminated bridges in this country. The bridges have been popular for low-volume road applications because they can be constructed with local wood species and labor.

Since stress-laminated bridges are relatively new, FPL has been monitoring many of these structures since 1988. The monitoring program was expanded in 1992 to include cooperative programs with FHWA. Reference 9 summarizes the performance of several of these bridges and reports on the performance of individual bridges. In general, the monitoring program includes recording bridge construction data, moisture content, stressing-bar force, vertical creep, load test behavior, and general condition evaluation.

Stress-Laminated Lumber Decks

Stress-laminated lumber decks are constructed by placing sawn lumber laminations on edge and stressing them with high-strength steel bars. For new construction, the bars are typically placed through holes that are predrilled at the center of the lamination. For bridge rehabilitation, the bars may also be placed on the top and bottom of the laminations. To develop the required compression and friction between the laminations, bars are tensioned to 134 to 356 kilonewtons (30,000 to 80,000 pounds force), depending on the bar size and spacing. Of this force, it is assumed that approximately 60 percent will be lost due to wood creep. Design provisions for stress-laminated lumber decks were published in 1991 as *AASHTO Standard Specifications for the Design of Stress-Laminated Wood Decks*.[10]

Depending on the size and grade of available lumber laminations, stress-laminated decks are generally used for clear spans of up to 11 m. All laminations need not be continuous over the span length, and butt joints are permitted with certain limitations.[10] Multiple-span crossings can be completed with a continuous span or a series of simple spans.

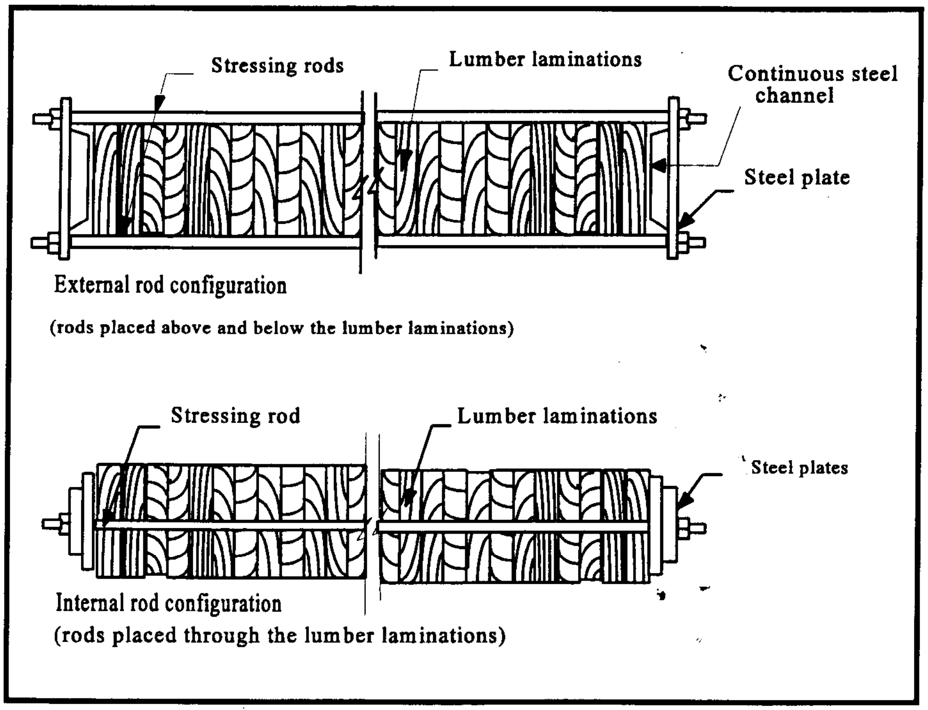


Figure 3 -Typical rod configuration for stress-laminated timber bridges.

Stress-Laminated T and Box Bridges

Stress laminating has also been extended to T- and box-section bridges constructed with glulam web members and sawn lumber flanges. Although numerous stress-laminated T and box bridges have been built, they are still considered experimental and unanswered questions about load distribution characteristics and economics remain. As such, design specifications for these bridges are not yet in the AASHTO specifications. The potential advantage of stress-laminated T and box bridges is their improved stiffness, which allows for longer spans. Research and field evaluation is continuing.

Stress-Laminated Glulam Deck Bridges

Stress-laminated glulam deck bridges are similar to stress-laminated lumber deck bridges, but the sawn lumber laminations are replaced with glulam beams. Because glulam provides higher design values and can be manufactured in larger sizes, longer spans are possible. The longitudinal glulam beams, typically 100 to 250 mm in nominal width, are placed side by side and stressed together transversely. The first application using this technology was in 1989 over the Teal River in Wisconsin. This bridge spans 9.9 m with a width of 7.2 m and carries two lanes of traffic.[11] Because these bridges have no butt joints, they provide improved load distribution characteristics when compared to stressed sawn lumber beam bridges with butt joints. The force retention in prestressing bars has also been better for the glulam bridges because the glulam is dry when installed. Since 1989, 15 stress-laminated glulam decks have been built using a variety of wood species for spans up to approximately 18 m. The bar force retention and overall performance of these bridges to date have been excellent.

Structural Composite Lumber Bridges

Structural composite lumber (SCL) includes laminated veneer lumber and parallel strand lumber. SCL is a relatively new material for bridge construction. Laminated veneer lumber consists of thin sheets of veneer that are glued together with the grain direction oriented primarily along the length of the member. Parallel strand lumber consists of small wood veneer or strand elements that are glued together with the grain parallel. Both types of SCL are highly engineered products that provide design values slightly higher than those typical of glulam. Because of lathe checks inherent in the individual veneers, SCL accepts treatment with wood preservatives very well, and this characteristic further enhances its utility as a bridge construction material. Although it has been used in building construction for more than 20 years, SCL has been used for bridges mostly in the last six years. Design provisions for SCL were included in the1995 interim specifications in the *AASHTO Standard Specifications for Highway Bridges.*

Individual SCL members in a longitudinal slab-type deck system are stressed together using the stress-laminating technique previously described for sawn lumber bridges. A more common system has been the use of T sections constructed of SCL. Using this design, solid T sections are manufactured from SCL and cambered to meet specific site conditions. The T sections are then placed side-by-side and are stress-laminated through the top flange. For dimensional stability, SCL box sections are typically placed along the bridge edges. To date, more than 30 of these bridges have been built and are providing excellent field performance. As with glulam, SCL permits longer spans due to the higher strength characteristics of the product as well as the availability of a wide range of sizes.

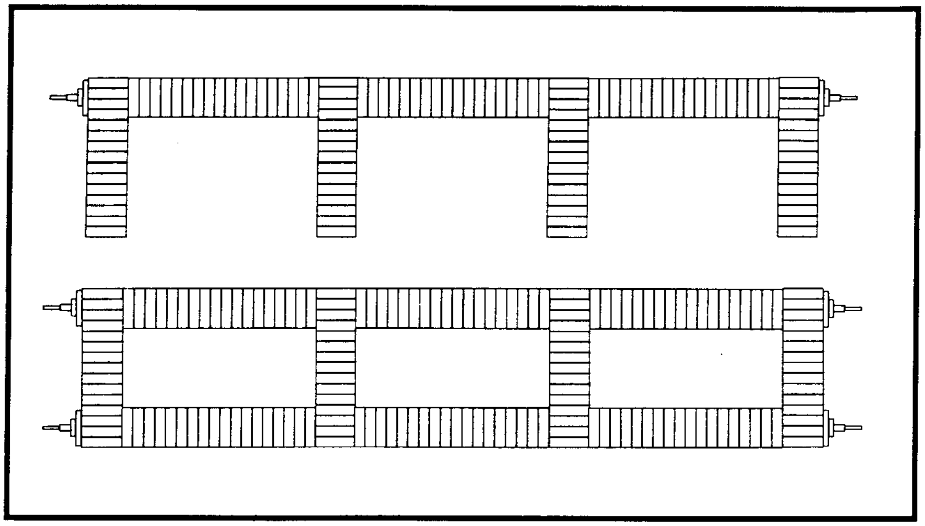


Figure 4 – Schematics of stress-laminated T- and box-section bridges.

National Timber Bridge Programs (renamed Wood in Transportation)

To encourage the use of wood in transportation structures, the U.S. Congress enacted two national programs. The Timber Bridge Initiative (TBI), passed by Congress in 1989, established a timber bridge program administered by the USDA Forest Service. Under the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), a similar program was established by FHWA. The key components of these programs have been demonstration bridges, research, and information transfer.

Demonstration Bridges

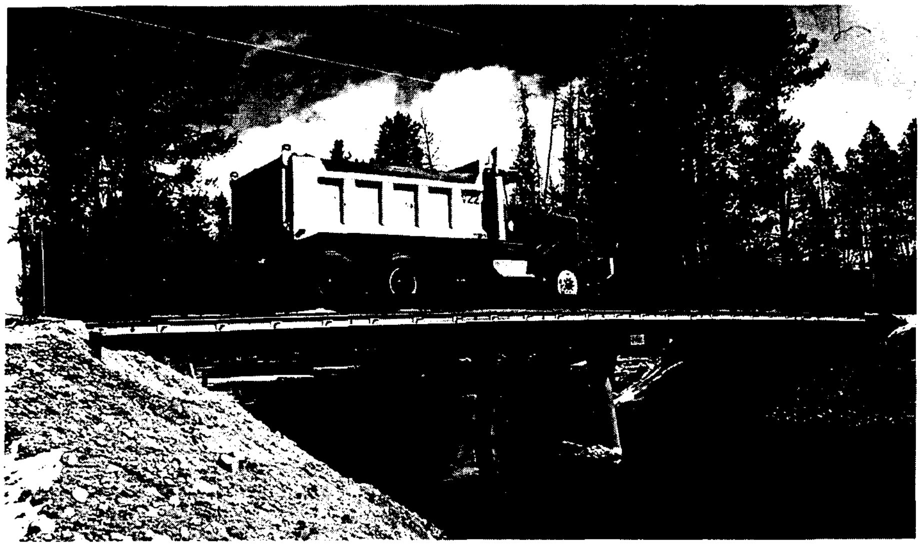
<u>Forest Service</u>

The Forest Service demonstration timber bridge program has been ongoing since 1989.[12] Under this program, local governments can receive up to 50 percent matching funds to construct timber bridges that demonstrate modern technology. The primary objectives have been to improve rural transportation infrastructure and provide an economic stimulus by using native wood species for bridges. To accomplish these objectives, demonstration bridges are selected through a competitive proposal process based on factors such as structural integrity, use of local labor and regional wood species, innovative design, and conformance to AASHTO standards. Bridges are evaluated by a national review panel whose members are knowledgeable in timber and related disciplines.

Since 1989, 316 vehicular bridges in 48 states and the District of Columbia have been funded. As of January 1996, approximately 203 bridges were completed and in service. From 1992 to 1996, the program also funded 43 pedestrian timber bridges. Through January 1996, the federal government provided $10,998,758 for the demonstration program, and matching funds from the recipients totaled $21,206,000. Separate Forest Service funds were used to construct approximately 323 timber bridges on National Forest System lands as a part of the annual bridge construction/replacement program.

<u>Federal Highway Administration</u>

Section 1039 of ISTEA established a



A structural composite lumber bridge over Kennally Creek (Idaho), 1991.

grants program for the construction of timber bridges. The 1993 appropriations bill modified ISTEA to allow construction grants for timber bridges on any public road eligible for the bridge program. State highway agencies select the candidates for the program and submit their proposals to FHWA for the final decision. These bridges must meet the eligibility criteria of the Highway Bridge Replacement and Rehabilitation Program (23 U.S. Code 144). Timber bridges built on the National Highway System (NHS) must conform to AASHTO standards for highway bridges, but bridges not on the NHS may be designed in accordance with the standards of the applicable state.

State-nominated projects are evaluated on several factors, including structural integrity, use of native timber species, innovative designs, and environmental factors. Funds are set aside from the FHWA Bridge Discretionary Program, and the receiving state must match at least 20 percent of the grant. A total of $7 million was authorized for fiscal year 1992. For fiscal years 1993 through 1997, the amount authorized was $7.5 million per year. At the beginning of fiscal years 1992, 1993, 1994, 1995, and 1996, grants were given to 34, 45, 27, 36, and 37 projects, respectively. The federal funding for these 5 years was $36,991,842, and this does not include the 20 percent matched by the receiving agencies.

Research and Technology Transfer

Although wood has been used for a number of years, there are issues that need to be addressed through research. Research funds are available to the Forest Service from the Timber Bridge Initiative and to FHWA from Section 1039 of ISTEA. To ensure a coherent research program, FPL and FHWA have implemented a joint national research program. Research activity is divided into six research areas identified in ISTEA:

Area I: System Development and Design.
Area II: Lumber Design Properties.
Area III: Preservatives.
Area IV: Alternate Transportation System Timber Structures.
Area V: Inspection/Rehabilitation.
Area VI: Technology and Information Transfer.

Research studies are cooperative studies with universities, local government agencies, and industry. In addition to the funding provided by the program, research organizations participating in the cooperative agreements must provide a match of at least 20 percent. Specific research projects are selected from the extensive survey of research needs conducted by Iowa State University and summarized in *Development of a Six-Year Research Needs Assessment for Timber Transportation Structures* (report number FPL-GTR-74). New studies are identified each year based on this report and are solicited through a competitive announcement. Several studies under way are summarized below.

- *Field performance of timber bridges* includes monitoring of each bridge typically for a two- to three-year period. The information obtained will be used to develop improvements in design, fabrication, and construction procedures.
- *Shear strength of sawn lumber beams* is aimed at determining the shear strength of non-checked and checked solid sawn lumber beams to develop AASHTO shear design criteria for beams subjected to edgewise bending.
- *Accelerated laboratory testing of new wood preservatives* is testing different wood preservatives that currently are in use or show promise for bridge applications. Accelerated testing using small wood beams is being conducted under laboratory and field conditions to determine efficacy for protecting various softwood and hardwood species with potential for use in timber bridges.
- *Manual on the use of wood preservatives for wood transportation structures* will provide a practical background on wood deterioration processes, wood preservatives, and environmental issues and guidelines for specifying and using treated wood. Information will be included for wood treaters, including recommendations for processes and procedures for treating wood for transportation structure applications.
- *Timber bridge rails* are being developed and crash tested to meet AASHTO and the National Cooperative Highway Research Program (NCHRP) criteria. When completed, several bridge rail systems will be available for use on longitudinal and transverse timber deck bridges.
- *Standard plans and specifications* are being developed for

several timber bridge types, including:

- Glulam beams with transverse glulam deck.
- Longitudinal glulam deck.
- Longitudinal stress-laminated deck.
- Longitudinal spike-laminated deck.
- Longitudinal nail-laminated deck.
- Transverse nail-laminated deck.
- Timber decks on steel beams.

A comprehensive summary of all the current research projects, including a summary of resulting publications, is prepared annually and is available from FHWA or FPL.[13]

Summary

The early American settlers used wood as the principal building material for their bridges. Although wood was slowly replaced by iron, steel, and concrete as building materials in the late 19th century and much of the 20th century, timber bridges continued to be built. However, not until the start of the Timber Bridge Initiative in 1989 has there been a renewed interest in wood as an alternative bridge material. The thrust of TBI and the ISTEA programs is to explore innovative methods for using wood for transportation structures. The early American bridges were covered bridges; however, with the development of improved wood preservatives, covering bridges is no longer necessary. Currently, there are effective preservatives that are approved by the Environmental Protection Agency, and through research, treatments are being extended for use on types of timber rarely used previously for bridge construction. Because wood is a biological material, it has many material and strength variabilities, both among and between species. Through engineered wood products, such as glued-laminated timber and structural composite lumber, many of these variables are substantially reduced. Wood is resistant to deicing chemicals and freeze/thaw cycles. If properly designed and constructed, timber bridges can carry the same loads as bridges built of any other material and will provide many years of acceptable performance. At this time, timber bridges are feasible for short- and medium-span structures, and research is being conducted to develop wood systems for longer span structures.

References

1. Robert Fletcher and J.P. Snow. “A History of the Development of Wooden Bridges,” Paper #186, *Proceedings of the American Society of Civil Engineers,* Vol.60, No. 8, Part 2, October 1934.
2. Fong L. Ou and Clyde Weller. “An Overview of Timber Bridges,” paper for presentation at the 65th Annual Meeting of the Transportation Research Board, Washington, D.C., January 1986.
3. *Standard Specificatious for Highway Bridges,* American Association of state Highway and Transportation Officials (AASHTO). Washington, D.C.
4. *National Design Specification for Wood Construction,* National Forest Products Association, Washington, D.C. (see current edition).
5. Michael A. Ritter. *Timber Bridges: Design, Construction, Inspection and Maintenance*, EM 7700-8, USDA-Forest Service, Washington, D.C., 1990.
6. *Book of Standards,* American Wood-Preservers’ Association (AWPA). Woodstock, Md.,1994.
7. Michael A. Ritter and T.G. Williamson. “State-of-the-Art Report: Glulam Timber Bridge Design in the U.S.,” paper presented at the International Council for Building Research Studies and Documentation, Working Commission W18-Timber Structures, Sydney, Australia, July 1994.
8. T.G. Williamson. “Glued-Laminated Timber for Bridge Construction,” *Wood Design Focus,* Vol. 1, No. 3, Fall 1990.
9. Michael A. Ritter, J.P. Wacker, and Sheila R. Duwadi. “Field Performance of Stress-Laminated Timber Bridges on Low-Volume Roads,” presented at the Sixth International Conference on Low-Volume Roads, Transportation Research Board, Minneapolis, Minn., June 1995.
10. *Standard Specifications for the Design of Stress-Laminated Wood Decks,* AASHTO, Washington, D.C., 1991.
11. J.P. Wacker, and Michael A. Ritter. *Field Performance of Timber Bridges, 1. Teal River Stress-Laminated Deck Bridge,* Publication Number FPL-RP-515, U.S. Department of Agriculture-Forest Service, Washington, D.C., 1992.
12. *The National Timber Bridge Initiative, Fiscal Year 1996, Status Report,* USDA-Forest Service. Washington, D.C.
13. Sheila R. Duwadi and Michael A. Ritter. *Status of Research on Timber Bridges and Related Topics,* Federal Highway Administration, Washington, D.C., 1995.

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