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Wood in Transportation Program

An Overview

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Research and demonstration bridge projects to further develop wood for transportation structures increased substantially in the United States in 1988 under a legislative action by the U.S. Congress known as the Timber Bridge Initiative. This program, renamed the Wood in Transportation Program, continues today and is administered by the Forest Service. FHWA became involved in timber bridge research in 1990. The FHWA program increased substantially under the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). From 1992 to 1997, ISTEA authorized significant funding for timber bridge research, technology transfer, and demonstration bridges. The current transportation authorization, the Transportation Equity Act for the 2lst century, does not contain a program for timber bridges similar to that of ISTEA; however, there are provisions under the fiscal year 1999 Transportation Appropriations Bill for advancing engineered wood and composites technology through research and demonstration projects to further develop the use of wood for transportation structures. As a result of these combined efforts, a large number of research projects have been initiated, and a number of demonstration bridges have been built under both programs. An overview of the research and the demonstration timber bridge programs is provided here.

The National Bridge Inventory (NBI) is a database kept by the FHWA of all vehicular bridges with a span length greater than 6.1 m on public roads in the United States. Based on this NBI database there are about 582,750 bridges, of which 38,298 are timber bridges and 39,503 are steel bridges with timber decks. In addition, about 3,500 of the 7,650 bridges in the National Forest System, as maintained by the Forest Service (FS), are timber bridges. Although wood is not the predominant material for building U.S. highway bridges, there are a vast number of timber bridges in the U.S. roadway system. Timber bridges provide a vital link on the secondary, local, and rural highways, which predominantly serve low volumes of traffic.

The NBI classifies highway bridges in three groups: the national highway system, the other federal-aid system, and the off-system bridges. The total number of bridges, along with the total number of timber bridges classified in these three roadway systems, is presented in Table 1. As indicated in Table 1, most timber bridges exist in the off-system and other federal-aid system highways; however, there remain over 400 timber bridges in the national highway system. Timber bridges are ideally suited in the short- to medium-span bridge range. Approximately 85,609 of the 175,885 deficient bridges in the NBI are short- to medium-span structures [less than 60 ft (18.29 m)] in which all three materials-timber, steel, and concrete--can be considered as alternative materials for replacement structures.

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Timber bridges have been used in the United States for hundreds of years; however, the use of these bridge types has declined in the 20th century. The national timber bridge programs have been successful in increasing public awareness of using wood as an alternative material for carrying modem-day highway loadings. Between 1988 and 1998 about 2,762 timber bridges were built, of which about 419 were demonstration bridges built as part of national programs.

CONGRESSIONAL LEGISLATION

The main incentive behind the national timber bridge legislation has been the need to revitalize local economies by finding means and methods for developing wood, especially the abundant supply of the underutilized wood species, for highway applications. Wood has proven to be a material suitable for transportation structures, as evidenced by the number of timber bridges in the country. However, it is necessary, as with any technology, to develop and advance the systems for changing needs. A large number of research projects have been initiated, and a number of demonstration bridges have been built under the timber bridge programs.

The FS has a long history of using timber for transportation applications. The National Forest System, using technology developed by the Forest Products Laboratory (FPL), designed and built some of the first glued-laminated timber bridges in the world. In 1986 the FS began to specifically focus on the national need of improving rural secondary roads by combining this knowledge and experience of the past with newer designs, research, and technology transfer efforts. In 1988, Congress funded the National Timber Bridge Initiative, currently known as the Wood in Transportation Program. Additionally, through the 1990 Farm Bill, Congress authorized the Secretary of Agriculture to continue the Modem Timber Bridge Initiative specifically to provide federal funds, on a cost share basis, for construction of demonstration bridges and technology transfer activities. Funding levels have ranged from $3.3 million in fiscal year (FY) 1989 to $400,000 in FY 1999.

The FHWA's principle role has always been to administer the federal-aid highway program, which typically has focused on roads and bridges on the more major highways. As timber bridges exist mostly on local and rural highways, the FHWA has had less involvement in those bridge systems. The FHWA's involvement in research with wood began in 1990. This timber bridge program grew substantially after the passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) legislation in 1991. ISTEA authorized significant funding from 1992 to 1997 for timber bridge research. technology transfer, and demonstration bridges. The funding level at the FHWA transfer has been $1,000,000 per year for timber bridge research and technology and $7,500,000 per year for demonstration bridges ($7,000,000 in FY 1992) from 1992 to 1997. According to

TABLE 1 Bridges in the National Bridges Inventory (February 1998)

ROADWAY SYSTEM	ALL BRIDGES	TIMBER BRIDGES
National Highway System	128,508	401
Other Federal-Aid	171,390	4,625
Off-system	282,852	33,272
Total	582,750	38,298

the FY 1999 Omnibus Appropriations Bill, approximately $1.5 million is available for research and innovative bridge applications involving engineered wood composites.

Although there are specific requirements set by each agency for determining the eligibility of demonstration bridge projects, the common factors for selection have been structural adequacy, longevity, serviceability, environmental sensitivity, economics, and design based on approved standards. Timber bridge research and technology transfer under ISTEA have been conducted under a joint national program between the FHWA and the FPL, in which the studies are based on a comprehensive summary of timber bridge research needs as reported by Wipf et al. (*1*).

DEMONSTRATION PROGRAMS

Most of the demonstration timber bridges have been built on secondary and local U.S. road systems. These new timber bridges are designed for the same AASHTO-specified bridge loadings as those of other materials such as steel and concrete. Most timber bridges are short-span structures (usually 6- to 12-m spans); however, longer span (over 30 m long) timber bridges and multiple simple-span timber bridges have also been built. Although the older designs such as covered bridges and nail-laminated bridges have been built as demonstration bridges, most have been newer designs such as glued-laminated timber bridges (Figure 1), stress-laminated bridges (Figure 2). dowel-laminated bridges, glued-laminated timber arches (Figure 3). and other state-of-the-art engineered wood bridges such as timber bridges reinforced with fiber-reinforced polymer (FRP) composites (Figure 4) and structural composite lumber. A number of stressed T's and stressed boxes have been built, although most of the stressed timber bridges have been deck types, which are built by either solid-sawed or glued-laminated timber members. The T's and boxes were developed to extend the stress-laminating concept to include longer-span timber structures. Longer spans have also been achievable by using stress-laminated glulam deck bridge designs.

FIGURE 2 Stress-laminated timber bridge.

The FHWA demonstration program has funded only vehicular bridges in which the main load-carrying member is wood. The number of proposals received annually at FHWA headquarters for funding the demonstration bridges varied over the 6-year period and ranged from 42 to 109 projects.

The FS demonstration program has funded both vehicular and pedestrian bridges. In addition, the FS program has funded a number of commercialization projects including several bridges under one grant and special projects including a preservative treatment facility. The number of proposals received by the FS for funding has generally been higher than at the FHWA. This may be attributable to the application process or to the priorities set by the state transportation agencies on utilizing the federal-aid highway bridge funds for these bridge types.

RESEARCH AND TECHNOLOGY TRANSFER PROGRAM

The national timber bridge research and technology transfer program is being conducted in the following areas, which are identified

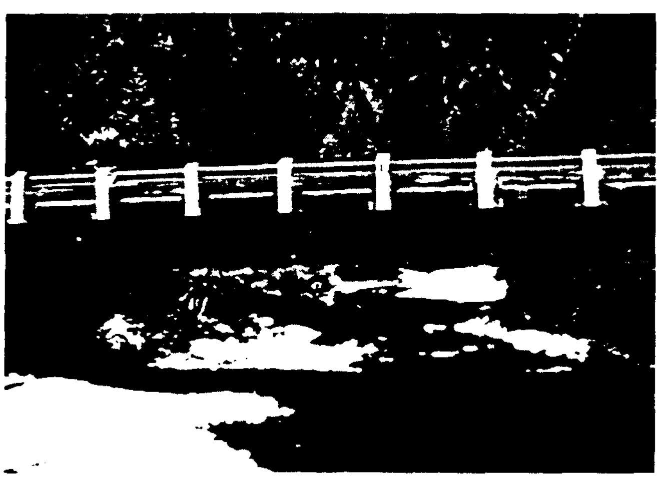

FIGURE 1 Glued-laminated timber bridge.

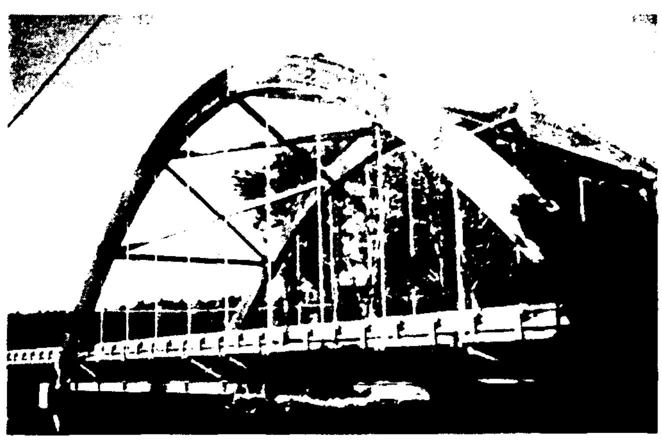

FIGURE 3 Glued-laminated timber arch bridge.

FIGURE 4 Glulam and FRP bridge.

in the ISTEA legislation: Area I, system development and design; Area II, lumber design properties; Area III, preservatives; Area IV, alternative transportation system timber structures: Area V, inspection and rehabilitation; and Area VI, technology and information transfer. The objective is to advance the state of the practice for the use of wood in transportation structures.

Currently, more than 44 studies have been initiated within these six areas at over 24 different research institutions across the country. Although there is basic research being conducted, the thrust of the program is to produce implementable products for use by the transportation agencies. These products range from standard plans, to inspection manuals, to crash-tested bridge rails. Summaries of research studies currently under way have been presented in a number of publications including *Summary of Bridge and Structures Related Research (2). Proceedings of the International Wood Engineering Conference (3), Proceedings of the Pacific Timber Engineering Conference (4),* and *Research Accomplishments for Wood Transportation Structures Based on a National Research Needs Assessment (5).* Following *is* an update of this ongoing research.

System Development and Design

Research studies conducted in this area will be used to refine and improve design, fabrication, and construction procedures and to formulate recommendations for changes in the design codes. With the start of the timber bridge programs, the states and counties were wanting to build new, innovative timber bridges. However, many of these newer design types had neither long-term performance data nor approved specifications. Therefore, a significant effort has been put forth to investigate the field performance of timber bridges under a national timber bridge monitoring program. These structures are located across the United States and include emerging timber bridge design technologies such as the stress-laminated bridges, glued-laminated timber bridges, structural composite lumber beam bridges, and glulam and FRP bridges. Reports on individual bridges are published as each monitoring project comes to an end. The publications are available on the Intemet (*6*) and from the National Wood in Transportation Information Center.

Other studies under way in this area include investigating the dynamic behavior of timber bridges due to vehicular loadings, assessing structural performance of timber bridges under seismic loadings, and developing alternative prestressing systems for the next generation of stressed timber bridges.

Following are the research studies started in this area:

- National timber bridge monitoring and evaluation including full-scale load testing;
- Field evaluation of a timber bridge constructed with metal plate connected trusses;
- Development of long-span timber bridge systems using glued-laminated timber;
- Development of stress-laminated truss bridges **using** light-frame metal plate connected trusses;
- Evaluation of cold-temperature effects on stress-laminated timber decks;
- Dynamic evaluation of timber bridges;
- Design optimization of T, bulb T, and box stressed timber bridges;
- Stress-laminated wood T and box beam bridge superstructures;
- Evaluation of alternative prestressing elements;
- Field performance of a stress-laminated timber bridge with E-glass FRP tendons;
- Effects of seismic loadings on timber bridges; and
- Utilization of structural composite lumber for bridge applications.

Lumber Design Properties

These research studies are aimed at developing engineering design criteria for structural wood products for use in highway bridges and at improving methods for characterizing lumber design properties. Studies under way have been aimed at improving the shear design criterion as it applies to nonchecked and checked solid-sawed lumber and to glued-laminated timber by determining whether there is a correlation between shear strength and beam size. Historically, shear strength properties of lumber have been determined from small, straight-grained, clear shear block specimens. However, controversies have existed about whether results from the shear block specimens are rep resentative of shear strength of structural beams or whether these small blocks account for local defects such as checks, splits, and knots present in full-sized beams. The findings of the shear study on solid-sawed Douglas fir beams are reported in research paper FPL-RR-553 (*7*). The final report on the glued-laminated timber decks is being prepared.

A second study in this area deals with determining the longitudinal modulus of elasticity (MOE) of in-place timber members within existing stress-laminated timber bridges by stress-wave nondestructive evaluation technology. Because of the variability of MOE within a lumber species and grade, field measurements of MOE in actual laminations are considered desirable for developing accurate models to determine the bridge behavior and load distribution under various field conditions and to determine any changes that may occur over time or due to the effects of preservative treatments. This study is nearing completion.

The third study in this area is aimed at refining the load and resistance factor design (LRFD) calibration factors for timber bridges currently given in AASHTO's LRFD Bridge Design Specifications. This is being accomplished through the development of load models, resistance models, reliability analysis, reliability indices, and calculation of resistance factors. The LRFD approach is intended to provide a rational basis for the design of bridge structures by providing the same level of safety for all members of a bridge.

Preservatives

The goal of this area of research is to develop or refine the preservative systems for use in highway timber bridges. Environmental issues and environmental concerns are a top priority in all these studies. The end products will be identifying emerging preservatives, establishing appropriate preservative retention, and identifying species and chemical combinations to protect timber transportation structures against deterioration caused by fungi and insects. Some studies, especially the laboratory studies and studies in which small samples are included, will be evaluated further through applications in actual structures to determine the effectiveness. In addition to preservatives, which are applied at the beginning, effective remedial treatments such as fumigants are also being studied for use during the life of a structure at the onset of deterioration, checking, splitting, and so forth. Information on leachability of preservatives and any environmental hazards it proposes will be available for use by the states. Lastly, a manual on wood preservatives is planned.

Specifically the following studies are under way in this area:

- Accelerated laboratory testing of new wood preservatives-ecosystem study,
- Accelerated laboratory testing of new wood preservatives-pure culture study,
- Accelerated testing of new preservatives,
- Preservative effects on stress-laminated southern pine bridge decks,
- Field treatment systems for protecting bridge members,
- Development of treatments and methods for field treating bridge members,
- Manual on wood preservatives for transportation structures,
- Treatability of heartwood,
- Copper naphthanate preservative for bridge applications, and
- Assessing environmental effects of wood preservatives used in timber transportation structures.

Alternative Transportation System Timber Structures

The research studies that have been conducted in this area have been directed toward the development of bridge rails and sound barriers. The development of crash-tested bridge rails for timber bridges was considered a high priority because many recognized that the static procedures for designing bridge rails were not adequately providing the performance characteristics when impacted by a vehicle, regulations were set requiring that only approved crash-tested bridge rails be used on those bridges built with federal highway funds, and there was only one crash-tested timber bridge rail system available.

Currently, the following bridge rail systems have been developed and successfully crash tested to meet AASHTO Performance Level 1 (PL-1) (8) criteria for use on a transversely laminated timber deck bridge:

- Glued-laminated timber rail without curb,
- Glued-laminated timber rail with curb,
- W-beam rail without curb, and
- Glued-laminated timber transition rail.

The PL-1 requires two crash tests to be conducted. one with a 2449-kg vehicle impacting the rail at 20°, 72 km/h: and the other with an 816-kg vehicle impacting the rail at 20°, 80 km/h. As PL-1 is seen to be equivalent to NCHRP 350 Test Level 2 (TL-2) (9), these rails have been accepted by the FHWA as meeting the TL-2 criteria.

In addition, the following bridge rail systems have been developed and successfully crash tested to meet AASHTO PL-1 and Performance Level 2 (PL-2) and NCHRP Report 350 Test Level 4 (TL-4) criteria for longitudinally laminated timber deck bridges:

- AASHTO PL-1 or NCHRP 350 TL-2 bridge rails
  - Glued-laminated timber rail with curb,
  - Glued-laminated timber rail without curb,
  - Steel rail without curb, and
  - Approach rail transition for a glued-laminated timber rail to a steel approach rail; and
- AASHTO PL-2 or NCHRP 350 TL-4 bridge rails
  - Glued-laminated timber rail with curb,
  - Steel rail without curb. and
  - Steel approach rail transition for use on the glued-laminated timber rail.

The PL-2 requires three tests consisting of impacting the rail with an 8165-kg vehicle at 15°, 80 km/h; a 2449-kg vehicle at 20°, 97 km/h; and an 816-kg vehicle at 20°, 97 km/h. The TL-4 requires three tests consisting of impacting the rail with an 820-kg vehicle at 20°, 100 km/h; a 2000-kg vehicle at 25°, 100 km/h; and an 8000-kg vehicle at 15°, 80 km/h.

The following three bridge railings were developed and crash tested to meet NCHRP TL-1 criteria and one for a lower test level based on criteria developed by the FS for single-lane bridges on very low volume roads:

- Top-mounted railing, TL-1;
- Side-mounted breakaway railing, TL-1;
- Curb railing, TL-1; and
- Low-volume curb railing.

The TL-1 requires two tests consisting of impacting the rail with an 820-kg vehicle at 20°, 50 km/h; and a 2000-kg vehicle at 25°, 50 km/h. The low-volume curb railing was tested with a 19.6-kN vehicle at 15°, 24 km/h.

Furthermore, with the crash-test data from earlier tests four timber bridge railings have been adapted for use on concrete decks. These include the following:

- Glulam timber rail with curb, TL-2;
- Glulam timber rail without curb. TL-2;
- Glulam timber rail with curb, TL-4; and
- Glulam timber curb rail, TL-1.

TL-2 requires two tests consisting of impacting the rail with an 820-kg vehicle at 20°, 70 km/h; and a 2000-kg vehicle at 25°, 70 km/h.

These have been approved by the FHWA for use on federally funded projects and are included in the FHWA approved list of bridge railings. Currently, a study is ongoing to develop bridge rails to **meet**

TL-4 and TL-2 requirements for transversely laminated timber deck bridges.

Highway noise is a constant problem, especially in urban areas. The wood sound barrier (Figure 5) will help alleviate this problem and will provide communities with an alternative to the noise wall systems that are currently available. Wood noise barriers blend more naturally with existing environmental surroundings and therefore can be softer and more pleasing to the eye. Recommended design criteria and designs for wood sound walls along with a set of standard plans will be available as a result of this study.

Inspection and Rehabilitation

The goal of this area of research is to develop effective, safe, and reliable methods for rehabilitating existing highway timber structures. Existing preservative systems and those being studied under this research program are intended to alleviate the problem of wood deterioration due to biotic agents. Often the problem lies not in the effectiveness of preservative systems but in not having the tools necessary to locate deterioration and thereby apply remedial treatments to prevent further degradation. The current state-of-the-practice for evaluation of timber bridges is through destructive or semidestructive means. Probing, coring, and drilling are all destructive or semidestructive methods that are used to verify deterioration or rot in timber members. The most common nondestructive means is sounding, in which the wood is impacted by a hammer and the sound that is produced is used to quantify the extent of deterioration. This process, however, requires someone with trained ears and is subject to individual interpretation depending on the experience of the inspector. Because of the need to advance current inspection techniques, emphasis has been given to identifying, developing, and evaluating promising nondestructive evaluation (NDE) techniques to accurately inspect and assess the structural integrity and remaining service life of timber bridge members.

The one NDE technique that has been used more than others for inspecting wood members is stress-wave technology. However, use of this technology remains limited because of a need for qualified personnel for equipment operation and data interpretation. Therefore, guidelines for equipment use and better interpretive procedures for evaluation of bridge components by using NDE stress waves is being prepared. More advanced inspection systems are also being explored to provide two- or three-dimensional, real-time images of the area inspected that are easier to interpret.

FIGURE 5 Wood noise barrier.

Other studies in this area include finding effective products for protecting timber members From moisture fluctuations, thereby reducing or preventing checking and splitting; finding effective wearing surfaces for timber decks; and developing an inspection manual for timber bridges.

Technology and Information Transfer

All reports and publications resulting from these studies will be made available to states, counties, and local transportation agencies. Standard plans and specifications for several types of timber bridge superstructures are nearing completion. All designs are being developed in accordance with the current Standard Specifications for Highway Bridges with AASHTO HS20 and HS25 loadings. The intent is to provide complete design, fabrication, and construction information. Design details and specifications will be available as half-sized drawings and on computer disks for use in computer-aided drafting systems. These plans will update the current FHWA standard plans for timber structures last revised in 1970.

In addition to these standard plans, the following design aids and manuals have been developed or are under development as tools for technology transfer:

- *Standard Plans for Southern Pine Bridges* (*10*).
- *Interactive Computer Programs for Wood Bridge Superstructures (under beta testing),*
- *Plans for Crash-Tested Bridge Railings for Longitudinal Wood Decks* (*11*),
- *Plans for Crash Tested Bridge Railings for Use on Transversely Laminated Wood Decks,*
- *Plans for Crash Tested Wood Bridge Railings for Concrete Decks* (*12*),
- *Plans for Crash Tested Bridge Railings for Longitudinal Wood Decks on Low Volume Roads* (*13*),
- *Manual for Timber Bridge Inspection* (under review), and
- *Preservatives Manual.*

A national conference and an international workshop have been held to further disseminate information related to wood utilization in transportation applications. The National Conference on Wood Transportation Structures, held in Madison, Wisconsin, on October 23-25, 1996, provided a forum for the exchange of state-of-the-art information on timber transportation structures. The proceedings of the National Conference on Wood Transportation Structures was prepared (*14*). An international workshop on timber and temporary bridges was held in conjunction with the PIARC (World Road Congress) sponsored International Seminar on Bridge Engineering and Management in Asian Countries in Jakarta, Indonesia, September 10-13, 1996.

The publications resulting from all these research studies will also be provided on compact discs and on the Internet.

SUMMARY

Historically. woods used for bridge construction in the United States have been softwoods. Hence, one of the main incentives for congressional legislation has been development and use of the underutilized hardwoods for bridge construction. This has been the focus of the timber bridge programs; however, because the programs are national in scope emphasis has been given to native species, which may include both hardwood and softwood species depending on the region. ISTEA funding for new research and demonstration projects ended in FY 1997; however, most of the research studies are ongoing with plans for completion within the next several years. Although limited in scope and funding, the current FHWA legislation includes provisions for development of the next generation of engineered wood-that is, hybrid glulam and fiber-reinforced wood composites-for vehicular bridge applications to be initiated in FY 1999. Funding for the FS Wood in Transportation Program is ongoing with the level of funding determined each fiscal year.

A publication (*5*) reassessing the research conducted to date based on the 1992 6-year research needs assessment (*1*), which has formed the basis of this joint research program, has been prepared. An update to this needs-assessment report to include new research needs statements for the next 5 to 6 years for wood transportation structures is under way. During the course of the FHWA/FPL program, both directly and indirectly, many advancements have occurred in the area of engineered wood structures for transportation uses. What was state-of-the-art at the beginning of the program is now more a state-of-the-practice. New advancements in engineered wood systems have led the way to newer designs that need further evaluation and study. New preservative systems that have been developed also need further evaluation and study.

Engineered wood products have dramatically changed the wood industry, yet use of these products in the transportation arena is relatively new. The engineered timber bridges of today are capable of carrying today's highway loadings. Design codes exist for designing these for the same AASHTO HS20 and HS25 truck loadings as for any other material. Many timber bridges exist on logging roads that carry even heavier loads. Because of the lack of interest and support, advancements in timber bridge technology for highway bridges has not occurred as rapidly as that for steel and concrete structures. The engineered wood products and the preservative systems available today can be used to develop newer designs and stronger and more durable products for highway applications. The engineered wood combined with other materials such as plastic composites is being used to develop hybrid products that are stronger and longer lasting. However, especially for emerging technologies, research needs to be continued to ensure that these new products and concepts function as intended. Wood has certain advantages such as being light weight, being resistant to freeze-and-thaw cycles, being resistant to deicing chemicals, and being one of the few renewable resources. The research and demonstration projects resulting from these programs are a major step toward advancing the state-of-the-practice for the use of wood in transportation applications.

REFERENCES

1. Wipf, T. J., M. A. Ritter, S. R. Duwadi, and R. C. Moody. *Development of Six-Year Research Needs Assessment for Timber Transportation Structures.* General Technical Report FPL-GTR-74. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wis., 1993.
2. *Summary of Bridge and Structures Related Research.* FHWA, http:// www.tfhrc.gov/structur/summary/summary.htm. 1998.
3. Ritter, M. A., R. C. Moody, and S. R. Duwadi. Summary of U.S. Research on Wood Transportation Structures. In *Proceedings of the International Wood Engineering Conference*, Vol. 1 (V. K. A. Gopu, ed.), New Orleans, La., 1996, pp. 81–88.
4. Ritter, M. A., R. Moody, and S. Duwadi. U.S. Timber Bridge Research. PTEC 94. *Timber Shaping the Future: Proceedings of Pacific Timber Engineering Conference*, Vol. 2, Gold Coast, Australia, 1994, pp. 148–155.
5. Ritter, M. A., and S. R. Duwadi. *Research Accomplishments for Wood Transportation Structures Based on a National Research Needs Assessment.* General Technical Report FPL-GTR-105. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wis., 1998.
6. Forest Products Laboratory website. http://www.fpl.fs.fed.us/wit/.
7. Rammer, D. R., L. A. Soltis, and P. K. Lebow. *Experimental Shear Strength of Solid-Sawn Douglas-Fir Beams.* Research Paper FPL-RP-553, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wis., 1996.
8. *Guide Specifications for Bridge Railings.* AASHTO, Washington, D.C., 1989.
9. Ross, H. E., Jr., D. L. Sicking, R. A. Zimmer, and J. D. Michie. *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features.* TRB, National Research Council, Washington, D.C., 1993.
10. Lee, P. D. H., M. A. Ritter, and M. Triche. *Standard Plans for Southern Pine Bridges.* General Technical Report FPL-GTR-84, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wis., 1995.
11. Ritter, M. A., R. K. Faller, P. D. H. Lee, B. T. Rosson, and S. R. Duwadi. *Plans for Crash-Tested Bridge Railings for Longitudinal Wood Decks.* General Technical Report FPL-GTR-87, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wis., 1995.
12. Ritter, M. A., R. K. Faller, P. D. H. Lee, B. T. Rosson, and S. R. Duwadi. *Plans for Crash Tested Wood Bridge Railings for Concrete Decks.* General Technical Report FPL-GTR-108, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wis., 1998.
13. Ritter, M. A., R. K. Faller, S. Bunnell, P. D. H. Lee, and B. T. Rosson. *Plans for Crash Tested Bridge Railings for Longitudinal Wood Decks on Low Volume Roads.* General Technical Report FPL-GTR-107, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wis., 1998.
14. Ritter, M. A., S. R. Duwadi, and P. D. H. Lee, eds. *National Conference on Wood Transportation Structures.* General Technical Report FPL-GTR-94, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wis., 1996.

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