

United States
Department of
Agriculture

Forest Service

Forest
Products
Laboratory

National
Wood in
Transportation
Information
Center

General
Technical
Report
FPL-GTR-105



In cooperation
with the

United States
Department of
Transportation

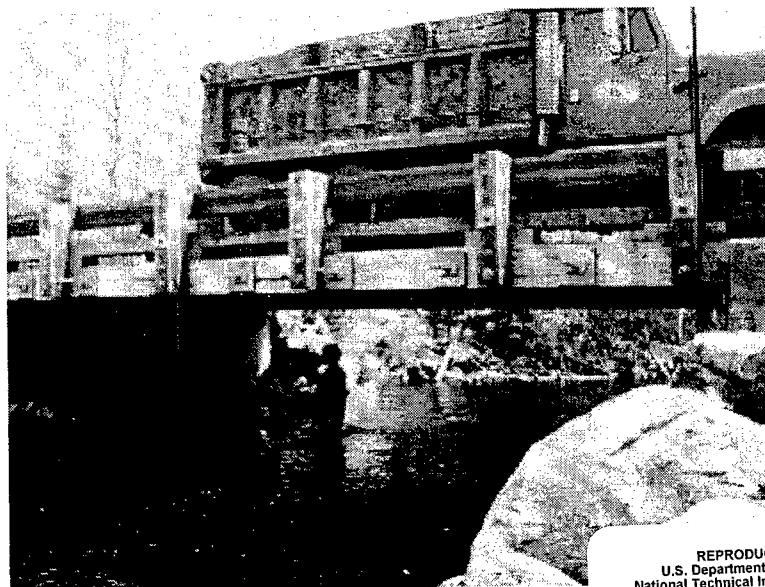
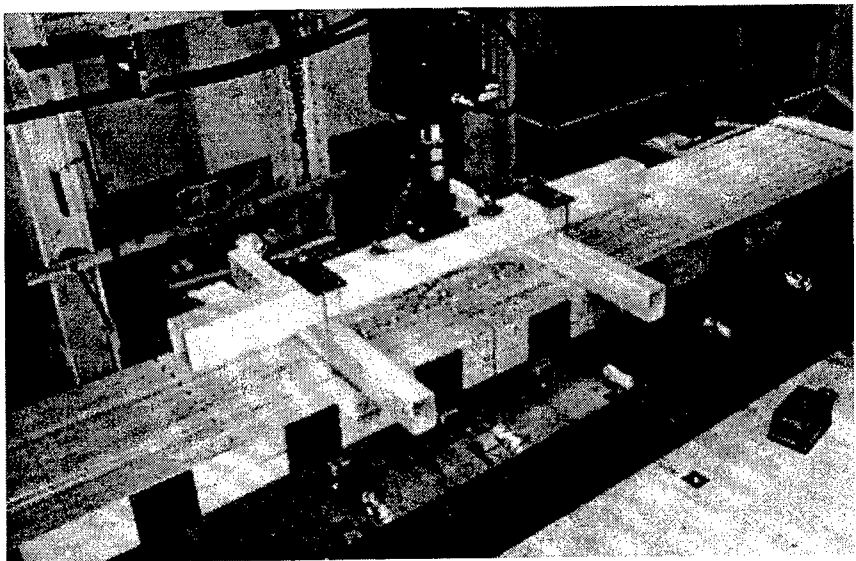
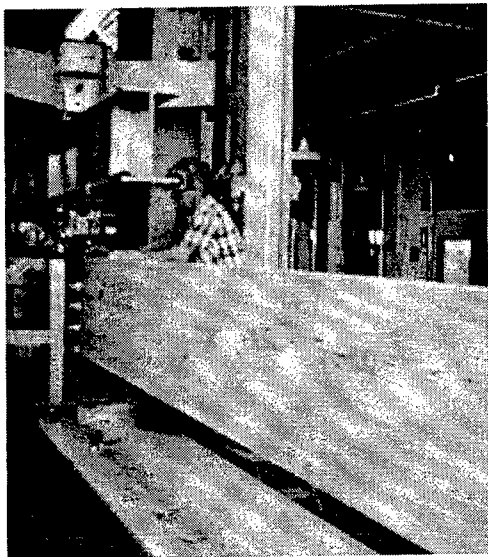
Federal
Highway
Administration



PB98-149453

Research Accomplishments for Wood Transportation Structures Based on a National Research Needs Assessment

Michael A. Ritter
Sheila Rimal Duwadi



REPRODUCED BY: **NTIS**
U.S. Department of Commerce
National Technical Information Service
Springfield, Virginia 22161

Abstract

In 1991, the USDA Forest Service, Forest Products Laboratory (FPL) and the Federal Highway Administration (FHWA) formed a joint cooperative research program for wood transportation structures. Development and execution of this program was based on a national assessment of research needs and priorities. In the 5 years since completion of the research needs assessment, significant research has been completed or is ongoing for wood transportation structures. This publication provides a summary of the research accomplishments of the joint FPL–FHWA research program for wood transportation structures.

June 1998

Ritter, Michael A.; Duwadi, Sheila Rimal. 1998. Research accomplishments for wood transportation structures based on a national research needs assessment. Gen. Tech. Rep. FPL–GTR–105. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 30 p.

A limited number of free copies of this publication are available to the public from the Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53705–2398. Laboratory publications are sent to hundreds of libraries in the United States and elsewhere.

The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

The use of trade or firm names is for information only and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

The United States Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, gender, religion, age, disability, political beliefs, sexual orientation, or marital or familial status. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (braille, large print, audiotape, etc.) should contact the USDA's TARGET Center at (202) 720–2600 (voice and TDD). To file a complaint of discrimination, write USDA, Director, Office of Civil Rights, Room 326-W, Whitten Building, 14th and Independence Avenue, SW, Washington, DC 20250–9410, or call (202) 720–5964 (voice and TDD). USDA is an equal employment opportunity employer.

Research Accomplishments for Wood Transportation Structures Based on a National Research Needs Assessment

Michael A. Ritter, Research Engineer
Forest Products Laboratory
Madison, Wisconsin

Sheila Rimal Duwadi, Research Structural Engineer
Federal Highway Administration
McLean, Virginia

Contents

	<i>Page</i>
Introduction.....	1
Objective and Scope.....	1
Research Accomplishments.....	1
Area I: System Development and Design.....	2
Fastener Design Criteria and Corrosion Protection.....	2
Structural Glued-Laminated Timber	3
Structural Composite Lumber	3
Design Aids	4
Timber Bridge Design Criteria	5
Timber Bridge Serviceability.....	7
Design Criteria for New Bridge Systems and Components.....	8
Area II: Lumber Design Properties.....	10
External Influences on Wood Properties.....	10
Wood Design Values and Properties.....	10
Lumber Grading and Yield.....	11
Composite Materials	12
Area III: Preservatives.....	13
Field Treatment.....	13
Preservative Effects on Material Properties.....	13
Environmental Considerations for Wood Preservatives.....	13
Preservation Methods and Chemicals	14
Preservative Application and Use.....	15
Area IV: Alternative Transportation System Structures.....	16
Bridge Rails	16
Retaining Structures.....	17
Noise Barriers.....	17
Area V: Inspection and Rehabilitation.....	17
Construction	17
Inspection and In-Place Evaluation.....	18
Structure Strength and Property Assessment.....	19
Maintenance and Rehabilitation	19
Area VI: Technology and Information Transfer.....	20
Information Distribution.....	20
Area VII: Other.....	21
Economics	21
Resource Utilization.....	21
Area VIII: Additional Projects.....	22
Bibliography	22

Introduction

In 1991, the USDA Forest Service, Forest Products Laboratory (FPL) and the Federal Highway Administration (FHWA) formed a joint cooperative research program for wood transportation structures. To effectively develop and execute this program, a summary of research needs based on input from a broad range of user groups was considered essential. To accomplish this summary, a cooperative research project was initiated with Iowa State University to prepare a comprehensive national summary of potential research studies and priorities. Results of this needs assessment identified 118 potential research studies and priorities that were subsequently published in Wipf and others (1993). This publication has served as the primary planning tool for research conducted under the joint FPL–FHWA wood transportation structures research program for fiscal years 1992 to 1997.

In the 5 years since completion of the research needs assessment, significant research has been completed or is ongoing for wood transportation structures. Much of this research has focused on developing crashworthy bridge railings, standardized design criteria and plans, nondestructive inspection methods and tools, evaluating new wood preservatives and application methods, and establishing field performance characteristics of newly constructed timber bridges. At the same time, the wood resource base has changed and the use of small secondary wood species has become more important for improved wood utilization. Given the research accomplishments and resource base changes, a revision of the research needs assessment was considered necessary to accurately reflect current and future priorities. Before efficiently completing such a revision, research accomplishments must be summarized to form a foundation for identifying future priorities. Summarizing accomplishments is also beneficial for evaluating the program in terms the needs previously identified.

Objective and Scope

The objective of this publication is to summarize the research accomplishments related to the potential studies and priorities identified in Wipf and others (1993). The scope of the accomplishments includes research that has been completed or initiated under the joint or individual research programs of FPL and FHWA. In several cases, research that was completed prior to the needs assessment is included if it relates directly to the identified potential studies.

Research Accomplishments

To provide a direct link with identified needs, research accomplishments in this report are presented in the same format as the research needs assessment. Overall, accomplishments are divided into the following general research areas identified in the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA). These research areas, including an area for other studies and an area for additional projects that do not fit those identified in ISTEA, were as follows:

- Area I: System Development and Design
- Area II: Lumber Design Properties
- Area III: Preservatives
- Area IV: Alternative Transportation System Structures
- Area V: Inspection and Rehabilitation
- Area VI: Technology and Information Transfer
- Area VII: Other
- Area VIII: Additional Projects

Within each of the general research areas, potential studies are grouped by subject. For each of those groups, a general research need statement is given. After this statement, the potential studies are listed as they appeared in the needs assessment with their overall priority from the needs assessment in parentheses to the left. Under the potential studies, the research accomplishments for that study are summarized and denoted with a bullet. If the research is completed, a brief statement of the outcome is given. If the research is in progress, the planned completion date is noted. In both cases, references are provided for publications resulting from the research.

In initiating research projects for the FPL–FHWA research program, every effort was made to follow the potential studies and priorities identified in the needs assessment. During the 5 years since the needs assessment was published, it was necessary to adjust priorities in some cases to complete research that was in progress prior to development of the needs assessment and to meet short-term program requirements. The listed accomplishments do not necessarily indicate that the identified need has been completely met. In many cases, the resolution of a specific need will require subsequent research to completely address all aspects of the issue. Also, in cases where no accomplishment is listed, a specific research project has not yet been initiated for that potential study.

Area I: System Development and Design

Fastener Design Criteria and Corrosion Protection

Research Need

Research is needed to determine the potential for corrosion of metal fasteners used in treated wood.

Potential Studies and Accomplishments

- (21) Develop methods for fastening wood decks to steel and concrete stringers for both new construction and for replacement decks.
 - Methods for attaching wood decks to steel stringers are included in the standard designs for timber bridge superstructures described later under Design Aids.
- (48) Evaluate the suitability of timber connections subjected to dynamic loading (fatigue).
- (60) Evaluate the suitability of galvanizing and epoxy coatings for providing corrosion protection for steel hardware used in timber bridge applications.
 - The suitability of galvanizing and epoxy coatings as a means of corrosion protection for steel stressing bars is being evaluated under numerous bridge field monitoring projects described in the Area I: System Development and Design section, under Timber Bridge Design Criteria and Design Criteria for New Bridge Systems and Components.
 - A manual has been developed with West Virginia University on the corrosion protection of steel components used in timber bridge applications (Davalos and Petro 1993a).
- (61) Evaluate the effects of wood preservatives on metal hardware and corrosion protection systems for metal hardware.
 - See the accomplishments for Potential Study (60) for related research in this area.
- (86) Develop new methods of providing corrosion protection for stress-laminated bridge stressing bars, including mechanical protection, epoxy coatings, galvanizing, and cathodic protection.
- (101) Evaluate the suitability of using toothed metal plate connectors (truss plates) in bridge components subjected to fatigue loading and cyclic moisture changes.
 - A three-phase study with the University of Maine has been completed to evaluate corrosion, fatigue, and cyclic moisture changes on the performance characteristics of metal-plate-connected trusses for use in bridge applications. Recommended design specifications will be developed and proposed to the American Association of State Highway and Transportation Officials (AASHTO) and other code organizations. The final report for all phases of the study is being prepared (Dagher and others 1995, 1996).

Structural Glued-Laminated Timber

Research Need

Additional information is needed to extend and improve structural glued-laminated (glulam) timber technology for transportation structure applications.

Potential Studies and Accomplishments

- (43) Evaluate the compatibility and relative bond strength of various adhesives used for glulam timber treated with different wood preservatives, both before and after gluing.
- (58) Develop technology for economical glulam timber manufactured from hardwood or secondary softwood species.
 - A study has been completed with West Virginia University to develop efficient glulam combinations using yellow-poplar lumber. As a result of this study, several glulam beam combinations were developed and industry standards were revised to reflect more efficient combinations. A demonstration bridge was also constructed (Moody and others 1993; Hernandez and others 1992, 1996).
 - A study has been completed with Pennsylvania State University to develop efficient glulam combinations using red oak and red maple lumber. As a result of that study, several glulam beam combinations were developed for each species and industry standards were revised to reflect more efficient combinations. Several bridges have also been constructed using red maple glulam combinations developed under that study (Janowiak and others 1995, Manbeck and others 1993, Shedlauskas and others 1996).
- (66) Investigate the feasibility of gluing wood treated with creosote or other oil-borne preservatives to improve treatment and durability of large glulam members.
- (92) Develop technology for glulam timber manufactured from mixed species.
 - Glulam using mixed red pine and Southern Pine was included in the construction of a stress-laminated deck bridge. This was an extension of technology previously developed at FPL (Wacker and Ritter 1992, Ritter and others 1993).

Structural Composite Lumber

Research Need

Additional information is required to evaluate the suitability of structural composite lumber and to develop specifications and standards for use in transportation structure applications.

Potential Studies and Accomplishments

- (31) Develop specifications and standards for the use of structural composite lumber, including laminated veneer lumber and parallel strand lumber in transportation structure applications.
 - Specifications for the use of structural composite lumber in bridge applications were developed in cooperation with the American Forest and Paper Association (AFPA) Timber Bridge Task Group and were submitted to and adopted by AASHTO in 1993 for inclusion in the AASHTO Standard Specifications for Highway Bridges.
- (32) Evaluate the suitability and performance characteristics of structural composite lumber in exposed bridge applications.

- Field evaluations and load testing have been completed on six stress-laminated T-beam bridges constructed of laminated veneer lumber (Ritter and others 1996b).
- A project is in progress with the University of Alabama to evaluate the field performance of a girder bridge constructed of parallel strand lumber. The project will be completed, and a final report is expected in 1999.
- A study has been initiated with the Florida A&M/Florida State University School of Engineering to evaluate performance of structural composite lumber under exterior bridge exposure conditions. The study will be concluded, and a final report is planned in 2000.
- A study is being initiated at the FHWA Turner Fairbank Highway Research Center to evaluate fatigue characteristics of full-sized bridge T-beams manufactured of structural composite lumber. The project is scheduled to be completed in 2000.

Design Aids

Research Need

Engineers need design aids specifically for the design of timber transportation structures.

Potential Studies and Accomplishments

- (2) Prepare standard designs, details, and specifications for designing timber bridge superstructures for minimum maintenance and long life.
 - A project has been completed with the University of Alabama and the Southern Forest Products Association to develop standard plans for several types of timber bridges constructed of Southern Pine lumber (Lee and others 1995, Lee and Wacker 1996).
 - A study is being completed with Laminated Concepts Inc. (Big Flats, NY) to develop standard plans and specifications for seven timber bridge superstructure types. Plans will be available in 1998 (Lee and Wacker 1996).
 - A project has been completed with West Virginia University to prepare a manual on design, construction, and quality control guidelines for stress-laminated timber bridge decks (Davalos and Petro 1993b).
- (5) Develop standard designs, details, and specifications for timber bridge superstructures.
 - See Potential Study (2) for related research in this area.
- (13) Develop standard designs, details, and specifications for timber bridge substructures and culverts.
 - A manual was prepared with West Virginia University on timber bridge substructures for bridge applications (Davalos and Petro 1994).
 - A project with the National Wood in Transportation Information Center will be initiated in 1998 to develop standard plans for timber substructures.
- (39) Adapt existing computerized bridge design programs (BRADD, MERLIN-DASH, etc.) to include timber bridges and timber bridge components.
 - See Potential Study (41) for related research in this area.
- (41) Develop interactive computer programs for the design of timber bridge systems and timber components used with other bridge materials.

- With the University of Wyoming, interactive design programs for the analysis, design, and rating of timber bridge superstructures are being developed. The program will include options for allowable stress design (ASD) and load and resistance factor and design (LRFD) specifications and is planned for completion in 1998 (Thomas and Puckett 1996).
- (65) Develop guidelines for economically optimizing material requirements for specific timber bridge types.

Timber Bridge Design Criteria

Research Need

Refinement and expansion of structural design criteria is needed for timber bridge systems currently included in AASHTO Standard Specifications for Highway Bridges.

Potential Studies and Accomplishments

- (15) Conduct field evaluations of existing structures to determine the load distribution characteristics of AASHTO-approved timber bridge systems to refine procedures and criteria for design and load rating.
- An extensive study involving field load testing and analytical evaluations has been completed with Iowa State University to determine the effects of dynamic vehicle loading on the strength and serviceability of timber bridges. Bridges in the study include stress-laminated decks, longitudinal glulam decks, and glulam girders with transverse glulam decks. Final published reports are expected in 1998, and recommendations will be made for revising the AASHTO Standard Specifications for Bridges (Wipf and others 1995, 1996; Ritter and others 1995f).
 - A study to perform field load testing and analytical investigations of longitudinal deck and glulam girder bridges is continuing. Included in that study is a cooperative project with the University of Alabama to load test girder bridges. A final report and recommendations for revised design criteria are planned for 1999.
 - A study has been completed with the University of Michigan to determine load distribution criteria of bridges constructed of lumber planks. A final report and recommended revisions to the AASHTO Standard Specifications for Bridges is being prepared for publication in 1998 (Nowak and Saraf 1996).
 - A study to investigate the analytical load distribution characteristics of glulam girder bridges with transverse decks has been completed with Gilham Engineering (Tualatin, OR). Results from that study will be used with load test results and further analytical evaluations by FPL and other cooperators to determine load distribution parameters for this bridge type.
 - The FPL–FHWA initiated a study to perform field load testing and analytical investigations of spike-laminated timber bridge decks. A final report and recommendations for revised design criteria is scheduled for 1999.
 - A study has been completed with West Virginia University to evaluate the relative stiffness of stress-laminated decks constructed of yellow-poplar lumber (Davalos and others 1996).
- (35) Study the means of obtaining composite action between timber beams and timber decks.
- (54) Conduct field evaluations of stress-laminated decks, constructed of various species and exposed to differing environmental conditions, to determine load distribution and performance characteristics.

- Field monitoring, evaluations, and load testing have been completed on numerous stress-laminated decks constructed of various wood species and materials and exposed to differing environmental conditions (Ritter and Oliva 1990; Ritter and others 1990a, 1991a, 1995c; Wacker and Ritter 1995c). Specific bridge projects include the following:
 - Big Erick's, MI; stress-laminated eastern hemlock lumber (Kainz and others 1996b)
 - Birchlog Run, WV; stress-laminated Southern Pine lumber (Wacker and Ritter 1995a)
 - Capitola S3, FL; stress-laminated Southern Pine lumber
 - Capitola S4, FL; stress-laminated Southern Pine lumber
 - Ciphers, MN; stress-laminated red pine lumber
 - Connell Lake, AK; stress-laminated Douglas-fir larch lumber (Hislop and Ritter 1996)
 - Cook County, MN; stress-laminated Douglas-fir lumber
 - Cooper Creek, IA; stress-laminated cottonwood lumber (Ritter and others 1995d,e; Lee and others 1996a)
 - Deans Bottom, IA; stress-laminated cottonwood lumber (Lee and others 1996a, 1997; Lee and Ritter 1997)
 - Decatur, IA; stress-laminated cottonwood lumber (Lee and others 1996a, 1997; Lee and Ritter 1997)
 - Graves Crossing, MI; stress-laminated red pine lumber (Wacker and Ritter 1995b)
 - Hibbsville, IA; stress-laminated cottonwood lumber (Lee and others 1996a, 1997; Lee and Ritter 1997)
 - Hoffman Run, PA; stress-laminated mixed hardwood lumber (Ritter and others 1996c)
 - Huntsman Road, OH; stress-laminated sawn lumber
 - Iron River, WI; stress-laminated Douglas-fir
 - Little Salmon, PA; stress-laminated red oak lumber (Ritter and others 1996a)
 - Lynches Wood's Park, SC; stress-laminated Southern Pine lumber (Wacker and others 1996a)
 - McCurdy Road, OH; stress-laminated Southern Pine lumber (Kainz and Hill 1996)
 - Mohawk Canal, AZ; stress-laminated Douglas-fir glulam (Lee and Lauderdale 1997)
 - Moose River, WI; stress-laminated Southern Pine glulam
 - Olean 30, NY; stress-laminated red maple lumber
 - Pueblo, CO; stress-laminated Douglas-fir lumber (Hislop 1998)
 - Putnam, GA; stress-laminated Southern Pine
 - Richland Center, WI; stress-laminated red pine glulam
 - Sanborn Brook, NH; stress-laminated Southern Pine lumber (Lee and others 1996b)
 - Schuyler, NY; stress-laminated hem fir and maple glulam
 - South Gila Canal, AZ; stress-laminated Douglas-fir glulam
 - Spirit Creek, GA; stress-laminated Southern Pine lumber
 - Sturgeon River, MI; stress-laminated Douglas-fir lumber
 - Teal River, WI; stress-laminated red pine/Southern Pine glulam (Wacker and Ritter 1992, Ritter and others 1993)
 - Tumbling Rock Run, WV, stress-laminated red oak lumber (Wacker and Ritter 1995a)
 - Wadesboro, FL; stress-laminated Southern Pine lumber
 - Weld County, CO; stress-laminated Douglas-fir lumber

- Based on field load testing and extensive analytical modeling, development of load distribution criteria for stress-laminated decks is currently being completed at FPL and will be proposed for adoption by AASHTO.
 - Laboratory and field evaluations have been completed to evaluate the effect of cold temperatures on the performance of stress-laminated timber decks. Results from those studies will be available in 1998 (Wacker and others 1996b).
- (75) Determine the level of lateral support provided for steel beams by different timber deck systems.
 - (82) Develop and field-evaluate new methods for shear transfer between glulam deck panels.
 - (87) Develop design criteria for timber arches and trusses for submission to AASHTO.
 - (93) Investigate and document the performance of timber bridges subjected to seismic loading.
- A study has been initiated with the National Center for Earthquake Engineering Research at the State University of New York-Buffalo to investigate the seismic performance of timber bridges and formulate design recommendations. The project is expected to be completed in 1999.

Timber Bridge Serviceability

Research Need

There is a need to develop serviceability design criteria for timber bridge systems, especially for live load deflection.

Potential Studies and Accomplishments

- (12) Develop designs and standards for long-lasting, waterproof, skid-resistant wearing surfaces for timber bridges.
 - A study is in progress with Virginia Polytechnic University to develop and evaluate waterproof asphalt wearing surfaces and membranes for timber bridge decks. The results of that study and the final report are expected to be available in 1998.
- (17) Investigate and define acceptable live load deflection criteria for various timber superstructure and deck types based on structural behavior, wearing surface performance, and human response.
- (50) Develop serviceability requirements for timber bridges based on use requirements.
 - As part of a project to investigate the dynamic performance of timber bridges, described in the Area 1: System Development and Design section under Timber Bridge Design Criteria, recommendations for serviceability requirements will be developed.
- (63) Develop methods for reducing live load deflection of AASHTO-approved timber bridge systems.
- (88) Evaluate the creep characteristics of longitudinal stress-laminated deck bridges.
 - Creep characteristics of stress-laminated decks are being investigated as part of the bridge monitoring studies described in the section Area 1: System Development and Design, under Timber Bridge Design Criteria.

Design Criteria for New Bridge Systems and Components

Research Need

New timber bridge systems should be developed that are structurally efficient and allow for the use of underutilized wood species.

Potential Studies and Accomplishments

- (20) Develop prefabricated, modular timber bridge systems that are easily transported for temporary applications.
 - A project is in progress with Auburn University to develop portable timber bridge systems for temporary access and bypass structures. Research results and standard plans for numerous types of portable timber bridges are scheduled to be available in 1999 (Taylor and others 1993, 1995, 1996; Taylor and Ritter 1996).
 - A study is in progress with Allegheny County, New York, to evaluate the field performance of a modular girder bridge constructed of red maple glulam. That study will be completed in 1999.
 - A project has been completed with the Forest Service San Dimas Technology Development Center (San Dimas, CA) to investigate portable timber surfaces for crossing unstable roadbeds (Hislop 1996).
- (55) Investigate the use of stress-laminated glulam T-beam and box-beam sections for longer spans.
 - A project has been completed at the University of Wisconsin-Madison to investigate the behavior of glulam T-beam and box-beam bridge sections. Publications may be obtained from the University of Wisconsin-Madison, Department of Civil and Environmental Engineering.
- (64) Develop methods and design criteria for post-tensioning timber beams and bridge systems.
 - A study has been initiated to evaluate the comparative performance of several types of prestressing elements for bridge systems including steel bars, strand, and bars constructed of fiber-reinforced polymer composites. That study is scheduled to be completed in 2000.
 - A study is in progress with the University of Maine to evaluate the field performance of a stress-laminated bridge constructed with fiber-reinforced polymer composite prestressing elements. That study will continue for 3 years and is expected to be completed in 2001 (Dagher and others 1997).
- (77) Develop design criteria for stress-laminated T-beam bridges through laboratory and field evaluations.
 - Field monitoring, field evaluation, and load testing have been completed on the following stress-laminated T-beam bridges:
 - Big Shoal, AR; Southern Pine glulam web, mixed hardwood lumber flanges
 - Cattaraugus County, NY; Southern Pine glulam web, mixed hardwood lumber flanges
 - North Siwell Road, MS; Southern Pine glulam web, Southern Pine lumber flanges
 - (Kainz 1998)
 - An independent study has been initiated with Auburn University to evaluate previous research and field evaluation of stress-laminated T-beam bridges. Based on that study,

recommendations will be formulated for design and performance criteria when the study is completed in 1998.

- A study is continuing with West Virginia University to evaluate the field performance of numerous stress-laminated T-beam bridges built in West Virginia (Dickson and GangaRao 1989).
 - A study has been completed with West Virginia University that evaluated the interaction between the web and flange of stress-laminated T-beam bridges using glulam webs and sawn lumber flanges. The study resulted in proposed methods to calculate stress distributions in the webs and flanges (Davalos and others 1994).
- (80) Develop methods and design criteria for longitudinally stress-laminating transverse timber bridges and decks.
- (85) Investigate methods for developing bolt-laminated beams and decks.
- A project with the University of Alabama to evaluate a bolt-laminated deck has been completed as part of the project to evaluate the field performance of a timber bridge constructed of metal-plate-connected wood trusses (Triche and others 1994, Triche and Ritter 1996).
- (100) Develop design criteria for stress-laminated box-beam bridges through laboratory and field evaluations.
- Field monitoring, field evaluation, and load testing has been completed on the following stress-laminated box-beam bridges:
 - Big Erick's, MI; Southern Pine glulam webs, Eastern Hemlock lumber flanges (Kainz and others 1996)
 - Christian Hollow, NY; Southern Pine glulam webs, mixed hardwood flanges (Wacker and others 1998)
 - Spearfish Creek, SD; Southern Pine glulam webs, Ponderosa pine lumber flanges (Wacker and others 1997)
 - An independent study has been initiated with Auburn University to evaluate previous research and field evaluation of stress-laminated box-beam bridges. Based on this study, recommendations for design and performance criteria will be formulated and are scheduled to be available in 1999.
 - A study is continuing with West Virginia University to evaluate the field performance of numerous stress-laminated box-beam bridges built in West Virginia.
- (110) Develop and field test bridges constructed of stress-laminated trusses manufactured with toothed metal plate connectors.
- A study has been completed with the University of Alabama to evaluate the field performance of the first bridge in the United States to be constructed of metal-plate-connected wood trusses. The final report for this project is planned for 1998 (Triche and others 1994, Triche and Ritter 1996).
 - A project with the University of Maine to evaluate the field performance of three bridges constructed with metal-plate-connected trusses will be completed in 1998, and the final report is expected in 1999 (Dagher and others 1995, 1996).

Area II: Lumber Design Properties

External Influences on Wood Properties

Research Need

The effect on wood properties of various external influences has not been clearly quantified for transportation structures applications.

Potential Studies and Accomplishments

- (29) Evaluate the effect of aging, moisture cycling, and repetitive loading on lumber stiffness.
 - A study at FPL is examining the effect of cyclic moisture changes between 19% and 9% on the properties of sawn lumber. That analysis will be completed in 1998, and a final report will be available in 1999.
- (46) Evaluate the effects of salt and deicing chemicals on the physical and mechanical properties of wood.
- (71) Evaluate the effect of cold temperature on the physical and mechanical properties of wood under static and dynamic loading conditions.
 - A study is in progress at FPL to determine the effect of temperature on the stiffness of green and dry sawn lumber for temperatures ranging from -10 to 150°F. Results will be available in 1999.
 - Laboratory and field evaluations have been completed to evaluate the effect of cold temperatures on the performance of stress-laminated timber decks. Results from these studies are scheduled to be available in 1998 (Wacker and others 1996b).
- (76) Determine the effect of moisture content on the properties of hardwood structural lumber.
 - A study is in progress at FPL to compare the bending strength and stiffness of sawn lumber at 15% and 6% moisture content. Testing for oak has been completed, and similar tests on softwoods and structural composite lumber are in progress. Results will be available in 1999.

Wood Design Values and Properties

Research Need

To fully develop the potential for efficient wood use in transportation structures, improved methods for assigning design values and better definitions of material properties are needed.

Potential Studies and Accomplishments

- (27) Refine horizontal shear design values and requirements for sawn lumber and glulam timber.
 - A study has been completed at FPL to investigate the shear strength of glulam timber beams. As a result of this study, plus additional work sponsored by the wood products industry, increased shear design values have been adopted by industry design specifications (Rammer and Soltis 1994, Soltis and Rammer 1994, Rammer 1996).
 - A study has been completed with Washington State University to evaluate the shear capacity of sawn lumber beams in both an unsplit and split condition. Final results from the study are planned in 1998 (Rammer and McLean 1996a,b; Rammer and others 1996).

- (47) Compile material resistance values for use in LRFD design for lumber, glulam, and timber piles.
 - A study is in progress with the University of Michigan to complete calibration of the wood design sections of the AASHTO LRFD Specification for Highway Bridges. As a part of that study, material resistance values will be reviewed and recommended revisions formulated. The study is expected to be completed with final recommendations in 1999 (Ritter and Williamson 1991, Ritter and Nowak 1994, Nowak and Ritter 1995).
- (81) Develop fatigue level (S-N) curves for softwood and hardwood lumber species.
- (83) Determine potential creep characteristics for lumber and glulam timber manufactured from softwood and hardwood.
- (89) Refine National Design Specification (NDS) properties for visually graded hardwood lumber through in-grade testing.
- (97) Refine methods of assigning property values to hardwood lumber based on the small, clear procedure.
 - A study has been completed at FPL to assess the structural properties of red oak and red maple lumber in bending, compression parallel to grain, and tension. Results indicate that significant increases in design values compared with those currently used are possible (Green and McDonald 1993a,b).
- (103) Refine duration of load adjustments for bridge applications.
 - Revised specifications for the design of timber bridges, including the duration of load adjustment factor for vehicle live load, were developed in cooperation with the AFPA Timber Bridge Task Group and adopted by AASHTO for inclusion in the AASHTO Standard Specifications for Highway Bridges.
- (111) Evaluate the volume effect on the strength and stiffness of hardwood structural lumber.

Lumber Grading and Yield

Research Need

More accurate procedures and equipment are needed to grade various species and determine potential log yield.

Potential Studies and Accomplishments

- (102) Develop economical, portable, reliable, and simple-to-use methods and equipment for machine grading hardwood and softwood lumber.
 - Several studies have been completed by FPL staff to improve grading of hardwood lumber through the use of mechanical grading techniques. As a result of those studies, it was found that the methods and procedures developed for softwood lumber are also applicable to hardwoods and one mill has been certified to produce machine-stress-rated hardwood lumber (Green and others 1994, 1996; Green 1997).
- (109) Develop quality control procedures appropriate for the mechanical grading of lumber from mixed species that are applicable to small mills.
- (115) Conduct grade and yield studies for hardwood logs, considering commercially viable species.

- A study has been completed by FPL staff to determine the potential yield of red oak and red maple structural lumber from graded hardwood logs. Results from that study provide the basic data needed by structural lumber producers when sawing hardwood logs (McDonald and Whipple 1992, McDonald and others 1993).
 - A study has been completed with West Virginia University to assess the potential for producing hardwood lumber bridge materials from log heart cants. The structural grade yield for six species including red oak, hickory, red maple, yellow-poplar, beech, and white oak was investigated (McDonald and others 1996).
 - A study is almost completed at FPL that determined the potential yield of machine-stress-rated lumber from beech, hickory, mixed maple, red oak, and yellow-poplar log heart cants. Results of that study are scheduled to be available in 1999.
- (117) Develop economical portable equipment to scan and evaluate the suitability of a log for structural lumber before it is cut.

Composite Materials

Research Need

The feasibility of developing composite materials made of wood and other materials such as steel and reinforced plastics needs to be determined.

Potential Studies and Accomplishments

- (70) Develop innovative methods of using steel, reinforced plastics, or other materials to improve strength and stiffness in timber components.
- See Potential Study (72) for related research in this area.
- (72) Investigate the potential for composite construction using timber with other nonwood materials.
- A pilot study has been completed with the University of Wyoming to investigate the feasibility of using prestressed fabric as a means of increasing the capacity of glulam beams. Preliminary results have been published (Galloway and others 1996).
 - A study has been completed in Clallum County Washington to evaluate the field performance of the first vehicle bridge constructed with glulam beams reinforced with fiber-reinforced polymer composite plates. A final report is expected in 1999.
 - A study is being initiated with University of Maine to evaluate the field performance of two bridges constructed of glulam beams reinforced with fiber-reinforced polymer composite plates. The study is planned to be completed 2001.
 - A study is continuing with West Virginia University to investigate the bonding characteristics of wood to fiber-reinforced polymer composites (Gardner and others 1994).
 - A study was completed with West Virginia University to investigate the potential increase in strength and stiffness using fiber-reinforced polymer composites in combination with yellow-poplar glulam. Results indicate that a strength gain of 26% and a stiffness gain of 18% is possible with 3% reinforcement (Hernandez and others 1997).
- (106) Develop methods for stress-laminating timber with other nontimber materials.
- A study is currently in progress with the Pennsylvania Department of Transportation to evaluate the field performance of five stress-laminated bridges constructed with hardwood

lumber laminations and steel plates. The project is a 5-year evaluation and will be concluded in 2001.

Area III: Preservatives

Field Treatment

Research Need

Improved methods are needed for field treating timber that is cut, drilled, or damaged during field construction or in service.

Potential Studies and Accomplishments

- (4) Develop guidelines on the effectiveness, use, and application of wood preservatives for field treating during fabrication and construction, especially for holes and other limited access areas.
 - A study is in progress with Oregon State University to develop a comprehensive manual and video tape on field treating with wood preservatives. These are scheduled to be available in 1998.
- (38) Develop guidelines for the effectiveness and use of wood preservatives and fumigants for in-place treating of deteriorated timber components.
 - A study has been initiated with Mississippi State University to evaluate various wood preservatives and fumigants as remedial treatments for timber transportation structures. The study will be concluded, and a final report will be available in 2000.
- (114) Evaluate the feasibility of developing small, mobile pressure treating units for applying wood preservatives.

Preservative Effects on Material Properties

Research Need

The effect of preservatives on the physical and mechanical properties of wood and metal hardware is relatively unknown and must be determined for transportation structure applications.

Potential Studies and Accomplishments

- (34) Evaluate the effects of chromated copper arsenate (CCA) and other water-borne preservatives on the physical and mechanical properties of wood.
- (40) Evaluate the effect of preservative treatment (chemicals and treating processes) on sawn lumber and glulam timber produced from hardwood species and structural composite lumber products produced from either hardwoods or softwoods.
- (51) Evaluate the suitability of water-borne preservatives for sawn lumber and glulam timber relative to the dimensional stability in exposed bridge applications.

Environmental Considerations for Wood Preservatives

Research Need

Better information is needed on environmental concerns related to the use and disposal of preservative-treated timber.

Potential Studies and Accomplishments

- (18) Evaluate the leachability and potential environmental hazards posed by wood preservatives used in exposed bridge applications.
 - A study is in progress with Oregon State University to evaluate the environmental effects of wood preservatives used for transportation structures. The study is scheduled to be completed and available in 2000.
- (26) Develop guidelines for the disposal or reuse of treated timber in accordance with the U.S. Environmental Protection Association (EPA) guidelines.
- (69) Investigate the potential for preservative treatment leaching and distribute information on the subject.
 - See Potential Study (18) for related research in this area.

Preservation Methods and Chemicals

Research Need

There is a need for improved wood preservation methods and chemicals based on new and existing technology.

Potential Studies and Accomplishments

- (6) Develop and test new wood preservative chemicals that do not pose adverse environmental hazards.
 - Studies are in progress with Oregon State University and Michigan Technological University to perform accelerated testing of new wood preservatives. Results from both studies will be available in 1998. The study with Michigan Technological University has been extended for an additional 5 years to allow collection and analysis of additional long-term data (Crawford and De Groot 1996; De Groot and others 1996, 1998; Laks and others 1996, 1997; Norton and others 1997).
 - A demonstration timber bridge was recently constructed using lumber treated with a new formulation of ammoniacal copper quat (ACQ) preservative. The performance of the bridge and preservative will be evaluated through an FPL–FHWA monitoring project, and the final report is planned for 2001.
- (42) Develop and evaluate alternative methods of wood preservation, other than chemical preservatives, that protect bridge components from moisture exposure and deterioration (coatings, shielding, composite materials, etc.).
 - A study is in progress with Pennsylvania State University to evaluate numerous coatings and coverings to protect exposed wood components and joints from moisture. That study is scheduled to be completed with a final report available in 1999.
 - A study is in progress at FPL to evaluate the effectiveness of several commercial roof coatings for protecting wood end grain from moisture. Results will be published in 2000.
- (59) Evaluate the effectiveness and develop guidelines and standards for water-repellent additives used in conjunction with water-borne preservatives for hardwood and softwood species.
 - A study has been completed with the Florida A&M–Florida State University School of Engineering to evaluate the relative performance of stress-laminated decks treated with CCA,

CCA with various water-repellent additives, and several oil-type preservatives. Final results of the study will be available in 1998 (Kainz and others 1996a).

- (78) Establish applicable penetration and retention requirements for the use of Copper Naphthenate in bridge components of softwood and hardwood sawn lumber and glulam timber.
 - A study is in progress with Michigan Technological University to determine the efficacy of the constituent components of copper naphthenate wood preservative. Results of that study, which will be completed in 1999, will be used to formulate recommended treating requirements.
- (79) Investigate the suitability of borate treatments for softwoods and hardwoods used in exposed bridge applications.
 - A study on the distribution of borates around point source insertions has been initiated at FPL. Results of laboratory investigations at the time of treatment are being evaluated. Field trials are in progress and are scheduled for completion in 1998.
- (105) Investigate the suitability and efficacy of existing preservative chemicals and treatment processes for applications involving hardwoods and secondary softwood species.
 - A study has been completed with the State University of New York to investigate the preservative treatment of red maple with a number of wood preservatives including CCA, ACQ, creosote, and copper naphthenate. Results indicate that there are substantial differences between heartwood and sapwood treatability and that oil-borne copper naphthenate was more effective than the water-borne formulation (Smith and others 1996).
 - A study has been completed with West Virginia University to evaluate the treatment of red maple and yellow-poplar with ACQ-B preservative. The heartwood of both species is difficult to treat, but heating the preservative improved penetration in yellow-poplar. This suggests that a combination of incising the wood and heating the preservative may lead to a commercially acceptable treatment process (Slahor and others 1997a).
 - A study has been completed with West Virginia University to evaluate the preservative treatment of Appalachian wood species for use in transportation structures. Better preservative penetration resulted at a moisture content of 12% than at higher moisture contents, and the woods treated better with creosote than with water-borne preservatives (Slahor and others 1997b).

Preservative Application and Use

Research Need

More information is needed regarding the application and use of wood preservatives.

Potential Studies and Accomplishments

- (22) Develop an informational summary on the restrictions, use recommendations, and use of wood preservatives.
 - A comprehensive manual on wood preservatives for transportation structures, which includes an informational summary on the restrictions, use recommendations, and use of wood preservatives, is currently being prepared and is scheduled to be available in 1999.

- (57) Develop guidelines on the treatability and applicability of various preservatives and treatment processes on the heartwood and sapwood of all commercially viable softwood and hardwood species.
 - A study is in progress with Michigan Technological University to investigate the treatability of heartwood with wood preservatives. Results of this study will be available in 1999 and will be used to develop recommended treating guidelines (Wang and De Groot 1996).
- (98) Investigate and revise existing treating standards to limit the quantity of untreatable heartwood and restate moisture content requirements to reflect maximum values rather than average values.
- (99) Develop base line treating cycles for hardwoods and other underutilized species.

Area IV: Alternative Transportation System Structures

Bridge Rails

Research Need

There is a need to develop and crash-test timber bridge rail systems that meet AASHTO specifications.

Potential Studies and Accomplishments

- (1) Develop crash-tested bridge rails for longitudinal and transverse timber decks, including approach rail transitions, at AASHTO PL-1 and PL-2.
 - A study has been completed with the University of Nebraska-Lincoln to develop crash-tested bridge rails and approach railing transitions for longitudinal wood decks in accordance with AASHTO PL1 and PL2 requirements. Additionally, a crash-tested railing for longitudinal wood decks has been developed that meets the new requirements of the National Cooperative Highway Research Program (NCHRP) Report 350, Test Level 4. Standard plans have been published (Ritter and others 1990b, 1991b, 1995a,b; Faller and others 1993, 1996; Ritter and Faller 1994).
 - A study has been completed with West Virginia University to develop three bridge rails at AASHTO PL1 for transverse glulam decks on glulam or steel beams. A glulam transition rail was also developed and crash-tested (Raju and others 1994).
 - A study is in progress with the University of Nebraska-Lincoln to develop crash-tested bridge railings and approach railing transitions for transverse wood decks in accordance with the requirements of NCHRP Report 350, Test Level 2 and Test Level 4. The project will be completed in 1999.
 - A project is being completed with the University of Nebraska-Lincoln to develop a computer model that will allow an analysis and evaluation of bridge railings to assess the crash worthiness of both existing and new designs. The project is scheduled to be completed in 1998.
 - A study is in progress with A.G. Lichtenstein & Associates (Paramus, NJ) and Pennsylvania State University to develop a timber bridge railing for historical timber bridges on the Delaware and Raritan Canal in New Jersey. The railing system will be developed to meet NCHRP Report 350 requirements and will be completed in 1998.
- (7) Develop crashworthy bridge rails for low-volume roads.

- A project has been completed with University of Nebraska-Lincoln and the USDA Forest Service Division of Engineering to develop four crashworthy bridge railings for low-volume roads. Three of these railings comply with the requirements for Test Level 1 as outlined in NCHRP Report 350. One of the railings complies with the Forest Service criteria for very low-volume roads. Published drawings will be available in 1998 (Faller and others 1995).

Retaining Structures

Research Need

There is a need for information on the design and performance of timber retaining structures.

Potential Studies and Accomplishments

(96) Develop standard designs for timber retaining walls and evaluate their field performance.

Noise Barriers

Research Need

Information is needed on the design and performance of timber noise barriers.

Potential Studies and Accomplishments

(112) Develop standard designs and evaluate the field performance of noise barriers constructed of timber and of timber combined with other materials.

- A study is being completed with Pennsylvania State University to evaluate the performance of noise barriers constructed of various materials and to develop standard designs and specifications for noise barriers constructed of wood and structural wood products. The final report and plans are scheduled to be available in 1998 (Boothby and others 1996).

Area V: Inspection and Rehabilitation

Construction

Research Need

Bridge engineers currently have a need for information regarding the fabrication, transportation, and construction of timber bridge systems.

Potential Studies and Accomplishments

- (9) Develop guide specifications for timber bridge construction.
- Specifications are included in standard plans and specifications developed in Design Aids in the Area 1: System Development and Design section.
- (30) Develop appropriate guidelines for fabrication, transportation, and storage of timber components and bridge systems.
- (36) Summarize methods of construction for various timber superstructures and substructures, including case histories.
- As a result of the bridge monitoring studies described in Timber Bridge Design Criteria in the Area 1: System Development and Design section, recommended construction practices for stress-laminated bridges have been published (Ritter and Lee 1996).

- (67) Develop a cost estimating guide for determining transportation, labor, and equipment requirements for timber bridge construction, based on time-in-motion studies of bridge construction projects.

Inspection and In-Place Evaluation

Research Need

Technology must be developed to accurately assess the in-place condition of wood transportation structures.

Potential Studies and Accomplishments

- (3) Develop economical, easy to use equipment and methods to conduct in-place nondestructive evaluation (NDE) of timber bridge components and develop standardized procedures and specifications for the NDE evaluation.
- A study has been completed with Washington State University to develop evaluation procedures and a comprehensive manual for the use of stress wave nondestructive evaluation of timber bridges. The final report will be available in 1998 (Pellerin and others 1994, 1995, 1996; Ross and Pellerin 1994).
 - A study is being completed that uses NDE techniques for measuring the stiffness of individual laminations in a stress-laminated deck. The techniques will provide information that will aid in assessing the physical and performance characteristics of stress-laminated bridges. A final report will be available in 1998 (Ross and others 1996).
 - A study has been initiated with Lawrence Livermore National Laboratory (Livermore, CA) to develop a hand-held prototype NDE tool based on micropower impulse radar technology for inspection of timber members. The study is scheduled to be completed in 2000.
 - A study has been completed with West Virginia University to investigate the feasibility and use of stress waves for determining the force level in bars for stress-laminated timber bridges (Chen and others 1994).
 - A study has been completed with West Virginia University to investigate the use of NDE for assessing the performance of unseasoned lumber. Results indicate that the techniques investigated provide good indications of the potential performance of unseasoned lumber and will aid in inspection as well as grading of wet wood-based materials (Halabe and others 1996, 1997).
- (8) Prepare a comprehensive manual for the inspection and evaluation of timber bridges.
- A study is currently being completed with the University of Tennessee to develop written guidelines for timber bridge field inspection and evaluation. Concurrent with this project, FPL is developing a comprehensive manual for timber bridge inspection and evaluation using conventional inspection techniques. Results from these projects will be available in 1998 and will supplement the FHWA Bridge Inspector's Training Manual.
- (16) Develop standardized methods for load testing and load rating existing timber bridges.
- (24) Refine inspection methods to more accurately detect incipient decay in timber bridge components.
- A study is currently in progress at Washington State University to develop and adapt new NDE methods and tools to timber bridge applications. That study is planned to be completed in 1999.

- (53) Develop methods for determining the embedment length of timber piles.

Structure Strength and Property Assessment

Research Need

Methods are needed to determine the residual strength and properties of deteriorated or damaged members in wood transportation structures.

Potential Studies and Accomplishments

- (45) Investigate methods for determining the post-decay strength of timber components.
- (56) Investigate and determine methods for evaluating the residual bending strength of beams that have split or failed in horizontal shear.
- (108) Develop methods for determining the residual strength of timber components that have undergone fire damage.

Maintenance and Rehabilitation

Research Need

The maintenance and rehabilitation of timber bridges is a concern to many engineers, and information regarding methods and techniques in this area is needed.

Potential Studies and Accomplishments

- (11) Prepare a comprehensive manual on maintenance practices for timber bridges.
- (19) Develop and evaluate economical, long lasting methods for sealing and protecting wood against moisture (especially end grain) when prolonged moisture exposure is likely to occur.
- A study is in progress with Pennsylvania State University to evaluate numerous coatings and coverings to protect exposed wood components and joints from moisture. The study is scheduled to be completed, and a final report available, in 1999.
- (37) Evaluate the suitability of wearing surface materials and geotextile fabrics to provide moisture protection to timber bridge decks.
- A study is in progress with Virginia Polytechnic University to develop and evaluate water-proof asphalt wearing surfaces and membranes for timber bridge decks. The results of this study with a final report are scheduled to be available in 1998.
- (44) Develop methods and comprehensive guidelines for restoring, increasing the capacity of, and replacing deteriorated timber components and piles used in bridges with an emphasis on accuracy and minimizing traffic disruption.
- (73) Develop methods to restore the capacity of beams that have horizontal shear failures.
- (84) Develop guidelines for the effectiveness and use of fumigants for in-place treating of deteriorated timber components.
- A study has been initiated with Mississippi State University to evaluate various wood preservatives and fumigants as remedial treatments for timber transportation structures. The study will be complete, and a final report available, in 2000.
- (95) Refine applications of stress-laminating to include the rehabilitation of existing components.

Area VI: Technology and Information Transfer

Information Distribution

Research Need

A better means of distributing information regarding timber transportation structures is needed.

Potential Studies and Accomplishments

- (33) Implement a mechanism for transferring timber bridge technology to users in a timely manner.
- The USDA Forest Service has established the National Wood In Transportation Information Center in Morgantown, WV. The center serves as a central point for information distribution related to wood transportation structures and is a primary source for FPL–FHWA research reports and publications.
 - A National Conference on Wood Transportation Structures was held in October 1997 to transfer technology related to recent developments in wood transportation structures. There were more than 160 conference participants, and proceedings were published (Ritter and others 1996e).
 - Internet sites have been established by FPL, the Turner-Fairbank Highway Research Center, and the National Wood in Transportation Information Center. These sites may be accessed at the following addresses:

Forest Products Laboratory site: <http://www.fpl.fs.fed.us/wit/>
National Wood In Transportation Information Center site: <http://wit.fsl.wvnet.edu>
Turner-Fairbank Highway Research Center site: <http://www.tfhrcc.gov>
 - A project has been initiated to develop two compact disks (CD's) containing publications related to wood transportation structures. The first CD will be available in 1998, and a second CD will be available in 2000.
 - Numerous published technical papers and reports have been prepared by FPL and FHWA staff and research cooperators to distribute current and emerging technology. In addition to the publications referenced to projects in this summary, there were also numerous other general papers presented at technical conferences, meetings, and workshops (Crews and others 1994; Duwadi and Ritter 1997; Moody 1994; Moody and Ritter 1990; Moody and others 1990; Ritter 1990; Ritter and Stanfill–McMillan 1995; Ritter and Williamson 1995a,b; Ritter and others 1994b; Taylor and Ritter 1994; Usuki and Ritter 1993).
- (62) Compile a summary of ongoing timber bridge research and distribute quarterly to interested parties.
- A summary of research under the joint FPL–FHWA Research Program has been prepared and distributed on an annual basis for the past 5 years and is also available on the internet sites previously discussed. In addition, research summary papers have been written and presented at numerous technical conferences (Ritter and Moody 1991; Ritter and others 1994a, 1996d; Duwadi and Ritter 1995).
- (68) Develop educational materials for use in colleges and trade schools.
- (90) Develop a data base of timber bridges, by type and material, that have been constructed in the United States and Canada during the past 30 years.

- Data bases of the bridges constructed under national demonstration timber bridge programs have been developed and are available from the USDA Forest Service and FHWA.

Area VII: Other

Economics

Research Need

A need exists for accurate information on timber bridge economics in such areas as initial cost, life-cycle costs, and design life.

Potential Studies and Accomplishments

- (14) Develop initial cost, life-cycle cost, and design life comparisons of timber bridges and culverts compared with steel and concrete bridges and culverts.
 - A study is being concluded with Michigan Technological University to examine the relative costs of timber bridges compared with those being constructed of reinforced concrete and structural steel. Results of that study and the final report will be available in 1998 (Sowards and others 1996).
 - An FPL analysis of the National Bridge Inventory and collaboration with similar studies elsewhere resulted in several publications regarding comparative timber bridge design life and performance (Smith and Stanfill–McMillan 1996, Stanfill–McMillan and Hatfield 1994, Stanfill–McMillan and Kainz 1995).
- (25) Develop guidelines for the relative cost and design life comparison of various types of timber bridges including composite construction.
- (28) Collect, analyze, and report bridge cost data obtained through the USDA Forest Service, FHWA, and state timber bridge demonstration projects.
 - Cost data summaries for bridges constructed under the Forest Service Demonstration Timber Bridge Program have been prepared and published by the National Wood In Transportation Information Center in Morgantown, WV.

Resource Utilization

Research Need

Studies should be performed to document the potential need for wood as a transportation material and effects of using local wood resources for the construction of transportation structures.

Potential Studies and Accomplishments

- (52) Compile and distribute information on the use of hardwoods and secondary softwoods in bridge applications.
- (104) Document experiences and lessons learned from using underutilized hardwood and secondary softwood species for bridge construction.
- (113) Document the economic multiplier effect realized when local materials and labor are used for transportation structures.
- (116) Complete an analysis of bridge needs in the United States for the next 30 years based on span and functional classification.

- (118) Evaluate the comparative energy requirements for the production and construction of timber, steel, and concrete bridges and culverts.

Area VIII: Additional Projects

The following projects were completed in addition to those resulting from the research needs assessment.

- A study was completed with Iowa State University and the Association of American Railroads to load-test two open-deck timber railroad bridges. A subsequent study was also completed with the same cooperators to load-test several timber bridges after rehabilitation or replacement using various options (Rogers and others 1996, 1997).
- A study has been initiated with Norfolk Southern Railroad to construct and evaluate a two-span stress-laminated timber railroad bridge. The bridge will be constructed and field evaluation will begin in mid-1998.

Bibliography

Boothby, T.E.; Manbeck, H.B.; Burroughs, C.B. [and others]. 1996. Development of wood highway sound barriers. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 158–167.

Chen, H.L.; He, Y.; GangaRao, H.V.; Ross, R.J. 1994. Field evaluations of prestress forces in post-tensioned rods using the dynamic characterization method. In: Structural materials technology. Proceedings, nondestructive testing conference; 1994 Feb. 23–25; Atlantic City, NJ.

Crawford, D.M.; De Groot, R.C. 1996. Evaluation of new creosote formulations.. In: Ritter, M.A.; Duwardi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 371–378.

Crews, K.; Ritter, M.; GangaRao, H.; Dickson, B. 1994. State of the art research—Stress-laminated timber bridge decks Australia and North America. In: PTEC 94 Timber shaping the future: Proceedings of Pacific timber engineering conference; 1994 July 11–15; Gold Coast, Australia. Fortitude Valley MAC, Queensland, Australia: Timber Research and Development Advisory Council; 2: 123–130.

Dagher, H.J.; Caccese, V.; Altimore, Y. [and others]. 1995. Using lightweight MPC wood trusses in bridges. In: Sanayei, M., ed. Restructuring: America and beyond: Proceedings of structures congress 13; 1995 April 2–5; Boston, MA. New York: American Society of Civil Engineers; 1: 9–12.

Dagher, H.J.; West, B.; Caccese, V. [and others]. 1996. Fatigue design criteria of MPC wood trusses for bridge applications. In: Ritter, M.A.; Duwardi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 58–64.

Dagher, H.J.; Abdel-Magid, B.; Ritter, M.A.; Iyer, S. 1997. GRP prestressing of wood decks. In: Kempner L. Jr.; Brown, C.B., eds. Building to last: Proceedings of structures congress XV; 1997 April 13–16; Portland, OR. New York, NY: American Society of Civil Engineers; 1: 585–589.

Davalos, J.F.; Petro, S.H. 1993a. Corrosion protection of steel hardware used in modern timber bridges. Rep. FHWA–RD–92–044. McLean, VA: U.S. Department of Transportation, Federal Highway Administration, Turner–Fairbank Highway Research Center. 42 p.

Davalos, J.F.; Petro, S.H. 1993b. Design, construction and quality control guidelines for stress-laminated timber bridge decks. Rep. FHWA–RD–91–120. McLean, VA: U.S. Department of Transportation, Federal Highway Administration, Turner–Fairbank Highway Research Center. 58 p.

- Davalos, J.F.; Petro, S.H.** 1994. Timber substructures for bridge applications. Rep. FHWA-RD-93-024. McLean, VA: U.S. Department of Transportation, Federal Highway Administration, Turner-Fairbank Highway Research Center. 100 p.
- Davalos, J.F.; GangaRao, H.V.S.; Sonti, S.S. [and others].** 1994. Bulb-T and glulam FRP beams for timber bridges. In: Baker, N.C.; Goodno, B.J., eds. Proceedings of Structures congress 12; 1994 April 24-28; Atlanta, GA. New York, NY: American Society of Civil Engineers; 2: 1316-1321.
- Davalos, J.F.; Sonti, S.S.; Shaik, S. [and others].** 1996. System stiffness for stress-laminated timber bridge decks. In: Gopu, V.K.A., eds. Proceedings of the international wood engineering conference; 1996 October 28-31; New Orleans, LA. Baton Rouge, LA: Department of Civil and Environmental Engineering, Louisiana State University; 1: 213-220.
- De Groot, R.; Crawford, D.; Woodward, B.** 1996. Integrated efficacy evaluation of new preservatives in alternative wood species. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. National conference on wood transportation structures; 1996 October 23-25; Madison, WI. Gen. Tech. Rep. FPL-GTR-94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 379-388.
- De Groot, R.C.; Evans, J.W.; Forsyth, P.G. [and others].** 1998. Soil-contact decay tests using small blocks: A procedural analysis. Res. Pap. FPL-RP-571. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 7 p.
- Dickson, B.; GangaRao, H.V.** 1989. Field monitoring of a stressed timber bridge over Elk Two-Mile Creek, West Virginia. In: The conference on bridges: Proceedings, 6th annual international bridge conference; 1989 June 12-14; Pittsburgh, PA. Pittsburgh, PA: Engineers' Society of Western Pennsylvania: 247-252.
- Duwadi, S.R.; Ritter, M.A.** 1995. Research on timber bridges and related topics: Research update. Washington, DC: Federal Highway Administration.
- Duwadi, S.R.; Ritter, M.A.** 1997. Timber bridges in the United States. *Public Roads*. 60(3): 32-40.
- Faller, R.K.; Ritter, M.A.; Holloway, J.C. [and others].** 1993. Performance level 1 bridge railings for timber decks. In: Transportation Research Record 1419. Washington, DC: Transportation Research Board, National Research Council: 21-34.
- Faller, R.K.; Rosson, B.T.; Sicking, D.L. [and others].** 1995. Design and evaluation of two bridge railings for low-volume roads. In: Proceedings, 6th international conference on low-volume roads; 1995 June 25-29; Minneapolis, MN. Washington, DC: National Academy Press; 2: 357-372.
- Faller, R.K.; Rosson, B.T.; Ritter, M.A. [and others].** 1996. Railing systems for longitudinal timber deck bridges. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23-25; Madison, WI. Gen. Tech. Rep. FPL-GTR-94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 145-157.
- Galloway, T.L.; Fogstad, C.; Dolan, C.W.; Puckett, J.A.** 1996. Initial tests of Kevlar prestressed timber beams. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23-25; Madison, WI. Gen. Tech. Rep. FPL-GTR-94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 215-224.
- Gardner, D.J.; Davalos, J.F.; Munipalle, U.M.** 1994. Adhesive bonding of pultruded fiber-reinforced plastic to wood. *Forest Products Journal*. 44(5): 62-66.
- Green, D.** 1997. New opportunities for mechanical grading of lumber. *Wood Design Focus*. 8(2): 21-24.
- Green, D.W.; McDonald, K.A.** 1993a. Investigation of the mechanical properties of red oak 2 by 4's. *Wood and Fiber Science*. 25(1): 35-45.
- Green, D.W.; McDonald, K.A.** 1993b. Mechanical properties of red maple structural. *Wood and Fiber Science*. 25(4): 365-374.

Green, D.W.; Ross, R.J.; McDonald, K.A. 1994. Production of hardwood machine stress rated lumber. In: Proceedings, 9th international symposium on nondestructive testing of wood; 1993 September 22–24; Madison, WI. Madison, WI: Conferences and Institutes, Washington State University—Forest Products Society: 141–150.

Green, D.; Kretschmann, D.; Wolcott, M.; Ross, R. 1996. Mechanical grading of timbers for transportation industry. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 186–191.

Halabe, U.B.; Bidigalu, G.M.; GangaRao, H.V.; Ross, R.J. 1996. Nondestructive evaluation of green lumber using stress wave and transverse vibration techniques. In: Thompson, D.O.; Chimenti, D.E., eds. Proceedings, Review of progress in quantitative nondestructive evaluation.. New York, NY: Plenum Press: 15: 1891–1894.

Halabe, U.B.; Bidigalu, G.M.; GangaRao, H.V.; Ross, R.J. 1997. Nondestructive evaluation of green lumber using stress wave and transverse vibration techniques. *Materials Evaluation*. 55(9): 1013–1018.

Hernandez, R.; Somnath, S.S.; Moody, R.C. 1992. Evaluation of yellow poplar glued laminated timber beams. ASAE Paper 92–4556. St. Joseph, MI: American Society of Agricultural Engineers. 12 p.

Hernandez, R.; Ritter, M.A.; Moody, R.C.; Lee, P.D.H. 1996. Yellow poplar glued-laminated timber: Product development and use in timber bridge construction. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 411–417.

Hernandez, R.; Davalos, J.F.; Sonti, S.S. [and others]. 1997. Strength and stiffness of reinforced yellow-poplar glued laminated beams. Res. Pap. FPL–RP–554. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 28 p.

Hislop, L.E. 1996. Portable surfaces for crossing unstable roadbeds. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 138–144.

Hislop, L.E.; Ritter, M.A. 1996. Field performance of timber bridges—7. Connell Lake stress-laminated deck bridge. Res. Pap. FPL–RP–550. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 13 p.

Janowiak, J.J.; Manbeck, H.B.; Hernandez, R. [and others]. 1995. Efficient utilization of red maple lumber in glued-laminated timber beams. Res. Pap. FPL–RP–541. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 23 p.

Kainz, J.A. 1998. Field performance of timber bridges—16. North Siwell Road stress-laminated bridge. Res. Pap. FPL–RP–570. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 17 p.

Kainz, J.A.; Hill, C.A. 1996. McCurdy Road stress-laminated timber bridge: A viable option for short-span design. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 418–426.

Kainz, J.A.; Ritter, M.A.; Yazdani, N.; Kadnar, J.O. 1996a. Effect of preservative treatment on bar force in stress-laminated bridge decks. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 245–251.

Kainz, J.A.; Wacker, J.P.; Nelson, M. 1996b. Field performance of timber bridges—9. Big Erick's stress-laminated deck bridge. Res. Pap. FPL–RP–552. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 24 p.

Laks, P.E.; Gutting, K.W.; Pickens, J.B.; De Groot, R.C. 1996. Field performance of new wood preservatives in secondary timber species. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 389–400.

Laks, P.E.; Gutting, K.W.; De Groot, R.C. 1997. Field performance of new wood preservative systems in secondary timber species. In: Proceedings, 28th annual meeting of the international research group on wood preservation; 1997 May 25–30; Whistler, Canada. Stockholm, Sweden: The International Research Group on Wood Preservation. Sec. 3. Wood Protecting Chemicals. IRG/WP 97–60077.

Lee, P.D.H.; Lauderdale, X. 1997. Field performance of timber bridges—13. Mohawk canal stress-laminated bridge. Res. Pap. FPL–RP–563. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 18 p.

Lee, P.D.H.; Ritter, M.A. 1997. Timber bridges in Southern Iowa. In: Kempner Jr., L.; Brown, C.B., eds. Building to last: Proceedings of Structures Congress XV; 1997 April 13–16; Portland, OR. New York, NY: American Society of Civil Engineers; Vol. 1: 295–299.

Lee, P.D.H.; Wacker, J.P. 1996. Standard plans for timber highway structures. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 344–350.

Lee, P.D.H.; Ritter, M.A.; Triche, M. 1995. Standard plans for Southern Pine bridges. Gen. Tech. Rep. FPL–GTR–84. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 26 p.

Lee, P.D.H.; Ritter, M.A.; Tice, E.D. 1996a. Eastern cottonwood stress-laminated timber bridges: enhancing rural America with underutilized species. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 104–113.

Lee, P.D.H.; Ritter, M.A.; Wacker, J.P. 1996b. Field performance of timber bridges—10. Sanborn Brook stress-laminated deck bridge. Res. Pap. FPL–RP–555. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 19 p.

Lee, P.D.H.; Ritter, M.A.; Golston, S.; Hinds, K. 1997. Field performance of timber bridges—14. Dean, Hibbsville, and Decatur stress-laminated deck bridges. Res. Pap. FPL–RP–564. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 21 p.

Manbeck, H.B.; Janowiak, J.J.; Blankenhorn, P.R. [and others]. 1993. Red maple glulam timber beam performance. Res. Pap. FPL–RP–519. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 30 p.

McDonald, K.A.; Whipple, J.W. 1992. Yield of 2 by 4 red oak stress-graded dimension lumber from factory-grade logs. Forest Products Journal. 42(6): 5–10.

McDonald, K.A.; Green, D.W.; Dwyer, J.; Whipple, J.W. 1993. Red Maple stress-graded lumber from factory-grade logs. Forest Products Journal. 43(11/12): 13–18.

McDonald, K.A.; Hassler, C.C.; Hawkins, J.E.; Pahl, T.L. 1996. Hardwood structural lumber from log heart cants. Forest Products Journal. 46(6): 55–62.

Moody, R. 1994. Timber bridges—A rebirth. Woodland Management. 15(4): 18–20.

Moody, R.; Ritter, M. 1990. Structural wood products. In: Suprenant, B.S., eds. Serviceability and durability of construction materials: Proceedings, 1st materials engineering congress; 1990 August 13–15; Denver, CO. New York, NY: American Society of Civil Engineers; Vol. 1: 41–52.

Moody, R.C.; Ritter, M.A.; GangaRao, H. 1990. Applications of wood materials for innovative bridge systems. In: Serviceability and durability of construction materials: Proceedings, 1st materials engineering congress; 1990 August 13–15; Denver, CO. New York, NY: American Society of Civil Engineers; Vol. 1: 423–432.

Moody, R.C.; Hernandez, R.; Davalos, J.F.; Sonti, S.S. 1993. Yellow poplar glulam timber beam performance. Res. Pap. FPL–RP–520. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 28 p.

Norton, J.; De Groot, R.C.; Kleinschmidt, S.; Crawford, D. 1997. The development of decay in untreated, second-growth Douglas-fir using two exposure techniques in North Queensland, Australia. In: Proceedings, 28th annual meeting of the international research group on wood preservation; 1997 May 25–30; Whistler, Canada. Stockholm Sweden: The Research Group on Wood Preservation. Sec. 2. Test Methodology and Assessment. IRG/WP 97–60077.

Nowak, A.S.; Ritter, M.A. 1995. Load and resistance factor design code for wood bridges. In: Proceedings, 4th International bridge engineering conference; 1995 August 28–30; San Francisco, CA. Washington, DC: National Academy Press; Vol. 2: 351–357.

Nowak, A.S.; Saraf, V. 1996. Reliability analysis of plank decks for bridges. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 225–231.

Pellerin, R.F.; Ross, R.J.; Falk, R.H.; Volny, N.J. 1994. Evaluation of timber bridges using stress wave technology. In: PTEC 94 timber shaping the future: Proceedings, Pacific timber engineering conference; 1994 July 11–15; Gold Coast, Australia. Fortitude Valley MCD, Queensland, Australia: Timber Research and Development Advisory Council; Vol. 1: 458–464.

Pellerin, R.F.; Ross, R.J.; Falk, R.H.; Volny, N.J. 1995. Evaluation of timber bridges using stress wave technology. In: Restructuring: America and beyond: Proceedings of Structures Congress 13; 1995 April 2–5; Boston, MA. New York: American Society of Civil Engineers; Vol. 1: 277–280.

Pellerin, R.F.; Lavinder, J.A.; Ross, R.J [and others]. 1996. In-place detection of decay in timber bridges—An application of stress wave technology. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 282–291.

Raju, P.R.; GangaRao, H.V.S.; Duwadi, S.R. 1994. Development and testing of timber bridge and transition rails for transverse glued-laminated bridge decks. In: Bridges, other structures, hydraulics and hydrology. Transportation Research Record No. 1460. Washington, DC: Transportation Research Board, National Research Council: 8–18.

Rammer, D.R. 1996. Shear strength of glued-laminated timber beams and panels. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 192–200.

Rammer, D.R.; McLean, D.I. 1996a. Recent research on shear strength in wood beams. In: Gopu, V.K.A., ed. Proceedings of the international wood engineering conference; 1996 October 29–31; New Orleans, LA. Baton Rouge, LA: Department of Civil and Environmental Engineering, Louisiana State University; Vol. 2: 96–103.

Rammer, D.R.; McLean, D.I. 1996b. Shear strength of wood beams. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 168–177.

Rammer, D.R.; Soltis, L.A. 1994. Experimental shear strength of glued laminated beams. Res. Pap. FPL–RP–527. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 38 p.

Rammer, D.R.; Soltis, L.A.; Lebow, P.K. 1996. Experimental shear strength of solid-sawn Douglas-fir beams. Res. Pap. FPL–RP–553. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 33 p.

Ritter, M.A. 1990. Development of stress-laminated concepts for timber bridges. In: Proceedings of the 8th Structures Congress; Abstracts; 1990 April 30; Baltimore, MD. New York, NY: American Society of Civil Engineers: 179–180.

Ritter, M.; Faller, R. 1994. Crashworthy bridge railing for longitudinal wood decks. In: PTEC 94 timber shaping the future. Proceedings of Pacific timber industry conference; 1994 July 11–15; Gold Coast, Australia. Fortitude Valley MAC, Queensland, Australia: Timber Research and Development Advisory Council; Vol. 2: 298–307.

- Ritter, M.A.; Lee, P.D.H.** 1996. Recommended construction practices for stress-laminated wood bridge decks. In: Gopu, V.K.A., ed. Proceedings of the international wood engineering conference; 1996 October 29–31; New Orleans, LA. Baton Rouge, LA: Department of Civil and Environmental Engineering, Louisiana State University; Vol. 1: 237–244.
- Ritter, M.A.; Moody, R.C.** 1991. Timber bridge research by the U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. In: Marcroft, J.C., ed. Proceedings of the 1991 international timber engineering conference; 1991 September 2–5; London, United Kingdom. High Wycombe, United Kingdom: Timber Research and Development Association; Vol. 3: 356–363.
- Ritter, M.A.; Nowak, A.S.** 1994. LRFD provisions for wood bridges. In: Baker, N.C.; Goodno, B.J., eds. Proceedings, Structures Congress 12; papers presented at the structures congress '94; 1994 April 24–28; Atlanta, GA. New York, NY: American Society of Civil Engineers; Vol. 1: 549–554.
- Ritter, M.A.; Oliva, M.G.** 1990. Field performance of U.S. stress-laminated wood bridges. In: Proceedings of the 1990 international timber engineering conference; 1990 October 23–25; Tokyo, Japan. Tokyo: Steering Committee of the International Timber Engineering Conference; Vol. 2: 564–569.
- Ritter, M.A.; Stanfill–McMillan, K.** 1995. Wood bridges in New England. In: Sanayei, M., ed. Restructuring: America and beyond: Proceedings of Structures Congress 13; 1995 April 2–5; Boston, MA. New York: American Society of Civil Engineers; Vol. 1: 1081–1084.
- Ritter, M.A.; Williamson, T.G.** 1991. LRFD design for wood bridges. In: Proceedings of the 9th Structures Congress; Structures Congress '91 compact papers; 1991 April 29; Indianapolis, IN. New York: American Society of Civil Engineers: 482–485.
- Ritter, M.A.; Williamson, T.G.** 1995a. Maintenance practices for wood bridges. In: Sanayei, M., ed. Restructuring: America and beyond. Proceedings of Structures Congress 13; 1995 April 2–5; Boston, MA. New York: American Society of Civil Engineers; Vol. 1: 290–293.
- Ritter, M.A.; Williamson, T.G.** 1995b. State of the art report: Glulam timber bridge design in the United States. Proceedings, 27th international council for building research studies and documentation: Working Commission W18—Timber Structures; 1994 July 27; Sydney, Australia. Universität Karlsruhe, Germany: Lehrstuhl für Ingenieurholzbau und Baukonstruktionen; 1–10.
- Ritter, M.A.; Geske, E.A.; Mason, L. [and others].** 1990a. Performance of stress-laminated bridges. Wood Design Focus. 1(3): 12–16.
- Ritter, M.A.; Post, E.R.; Faller, R.K.** 1990b. Vehicular railing systems for timber bridges: A program overview. Wood Design Focus. 1(4): 4–7.
- Ritter, M.A.; Geske, E.A.; McCutcheon, W.J. [and others].** 1991a. Methods for assessing the field performance of stress-laminated timber bridges. In: Proceedings of the 1991 International timber engineering conference; 1991 September 2–5; London, United Kingdom. London, United Kingdom: TRADA; Vol. 3: 3.319–3.326.
- Ritter, M.A.; Post, E.R.; Faller, R.K.** 1991b. Crashworthy railing systems for timber bridge decks. In: Proceedings, 9th Structures Congress; Structures Congress '91 Compact Papers; 1991 April 29; Indianapolis, IN. New York: American Society of Civil Engineers: 540–543.
- Ritter, M.A.; Wacker, J.P.; Stanfill–McMillan, K.; Kainz, J.A.** 1993. Development and evaluation of the Teal River stress-laminated glulam bridge. In: Transportation Research Record 1426. Washington, DC: Transportation Research Board, National Research Council: 27–35.
- Ritter, M.A.; Williamson, T.G.; Moody, R.C.** 1994b. Innovations in glulam timber bridge design. In: Baker, N.C.; Goodno, B.J., eds. Proceedings, Structures Congress 12; papers presented at the structures congress '94; 1994 April 24–28; Atlanta, GA. New York, NY: American Society of Civil Engineers; Vol. 2: 1298–1303.
- Ritter, M.A.; Faller, R.K.; Duwadi, S.R.** 1995a. Crash-tested bridge railings for timber bridges. In: Proceedings, 4th International bridge engineering conference; 1995 August 28–30; San Francisco, CA. Washington, DC: National Academy Press; Vol. 2: 395–404.

Ritter, M.A.; Faller, R.K.; Lee, P.D.H. [and others]. 1995b. Plans for crash-tested bridge railings for longitudinal wood decks. Gen. Tech. Rep. FPL–GTR–87. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 27 p.

Ritter, M.A.; Wacker, J.P.; Duwadi, S.R. 1995c. Field performance of stress-laminated timber bridges on low-volume roads. In: Proceedings, 6th International conference on low-volume roads; 1995 June 25–29; Minneapolis, MN. Washington, DC: National Academy Press; Vol. 2: 347–357.

Ritter, M.A.; Wacker, J.P.; Tice, E.D. 1995d. Design, construction, and evaluation of timber bridge constructed of cottonwood lumber. In: Proceedings, 4th International bridge engineering conference; 1995 August 28–30; San Francisco, CA. Washington, DC: National Academy Press; 2: 358–370.

Ritter, M.A.; Wacker, J.P.; Tice, E.D. 1995e. Field performance of timber bridges—2. Cooper Creek stress-laminated deck bridge. Res. Pap. FPL–RP–536. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 17 p.

Ritter, M.A.; Wood, D.J.; Wipf, T.J. [and others]. 1995f. Dynamic response of stress-laminated-deck bridges. In: Proceedings, 4th International bridge engineering conference; 1995 August 28–30; San Francisco, CA. Washington, DC: National Academy Press; Vol. 2: 381–394.

Ritter, M.A.; Kainz, J.A.; Porter, G.J. 1996a. Field performance of timber bridges—5. Little Salmon Creek stress-laminated deck bridge. Res. Pap. FPL–RP–547. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 15 p.

Ritter, M.A.; Lee, P.H.; Kainz, J.; Meyer, C. 1996b. Evaluation of stress-laminated T-beam bridges constructed of laminated veneer lumber. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 92–103.

Ritter, M.A.; Lee, P.D.H.; Porter, G.J. 1996c. Field performance of timber bridges—6. Hoffman Run stress-laminated deck bridge. Res. Pap. FPL–RP–549. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 16 p.

Ritter, M.A.; Moody, R.C.; Duwadi, S.R. 1996d. Summary of U.S. research on wood transportation structures. In: Gopu, V.K.A., ed. Proceedings of the international wood engineering conference; 1996 October 28–31; New Orleans, LA. Baton Rouge, LA: Department of Civil and Environmental Engineering, Louisiana State University; Vol. 1: 81–88.

Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. 1996e. National conference on wood transportation structures. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 494 p.

Rogers, P.; Wipf, T.; Ritter, M.; Otter, D.E. 1996. Superstructure load path testing of two open-deck timber bridges. Technology Digest—Association of American Railroads Railway Technology Department. TD 96(027).

Rogers, P.; Otter, D.E.; Wipf, T. [and others]. 1997. Effectiveness of glued laminated components in strengthening timber bridges. Technology Digest—Association of American Railroads Railway Technology Department. TD 97(026).

Ross, R.J.; Pellerin, R.F. 1994. Nondestructive testing for assessing wood members in structures: A review. Gen. Tech. Rep. FPL–GTR–70 (Rev.). Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 40 p.

Ross, R.J.; Ritter, M.A.; Schad, K.C. 1996. Determining in-place modulus of elasticity of stress-laminated timber decks using NDE. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 277–281.

Shedlauskas, J.P.; Manbeck, H.B.; Janowiak, J.J. [and others]. 1996. Efficient use of red oak for glued-laminated beams. Transactions of the ASAE. 39 (1): 203–209.

Slahor, J.J.; Hassler, C.C.; De Groot, R.C.; Gardner, D.J. 1997a. Preservative treatment evaluation of red maple and yellow poplar with ACQ-B. *Forest Products Journal*. 47(4): 50–54.

Slahor, J.J.; Hassler, C.C.; De Groot, R.C.; Gardner, D.J. 1997b. Preservative treatment evaluation with CCA and ACQ-B of four appalachian wood species for use in timber transportation structures. *Forest Products Journal*. 47(9): 33–42.

Smith, R.L.; Stanfill-McMillan, K. 1996. Perception versus reality: An analysis of timber bridge performance in the United States. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. *Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94*. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 467–475.

Smith, W.B.; Abdullah, N.; Herdman, D.; De Groot, R.C. 1996. Preservative treatment of red maple. *Forest Products Journal*. 46(3): 35–41.

Soltis, L.A.; Rammer, D.R. 1994. Shear strength of unchecked glue-laminated beams. *Forest Products Journal*. 44(1): 1–8.

Sowards, G.M.; Wang, J.Z.; Orr, B.; Stanfill-McMillan, K. 1996. National cost study of timber bridges. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. *Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94*. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 480–489.

Stanfill-McMillan, K.; Hatfield, C.A. 1994. Performance of steel, concrete, prestressed concrete and timber bridges. In: *Developments in short and medium span bridge engineering '94. Proceedings of bridge management; 1994 August 8–11; Halifax, Nova Scotia. Montreal, Canada: Canadian Society for Civil Engineering: 341–354.*

Stanfill-McMillan, K.; Kainz, J.A. 1995. Factors influencing timber bridge performance. In: Sanayei, M., ed. *Restructuring: America and beyond: Proceedings of Structures Congress 13; 1995 April 2–5; Boston, MA. New York: American Society of Civil Engineers; Vol. 1: 294–297.*

Taylor, S.E.; Ritter, M.A. 1996. Portable T-section glulam bridge for low-volume roads. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. *Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94*. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 427–436.

Taylor, S.E.; Ritter, M.A.; Murphy, G.L. [and others]. 1993. Portable timber bridge designs for low volume forest roads. *ASAE Paper 93–7511*. St. Joseph, MI: American Society of Agricultural Engineers. 14 p.

Taylor, S.E.; Keliher, K.P.; Thompson, J.D. [and others]. 1995. Portable glulam timber bridge design for low-volume forest roads. In: *Proceedings, 6th International conference on low-volume roads; 1995 June 25–29; Minneapolis, MN. Washington, DC: National Academy Press; 2: 328–338.*

Taylor, S.E.; Ritter, M.A.; Keliher, K.P.; Thompson, J.D. 1996. Portable glulam timber bridge systems. In: Gopu, V.K.A., ed. *Proceedings of the international wood engineering conference; 1996 October 29–31; New Orleans, LA. Baton Rouge, LA: Department of Civil and Environmental Engineering, Louisiana State University; 2: 368–375.*

Thomas, W.R.; Puckett, J.A. 1996. Analysis, design, rating, and drafting of wood bridge superstructures. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. *Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94*. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 361–370.

Triche, M.H.; Ritter, M.A. 1996. Pole Creek metal-plate-connected truss bridge. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. *Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94*. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 49–57.

Triche, M.H.; Ritter, M.A.; Lewis, S.L.; Wolfe, R.W. 1994. Design and field performance of a metal-plate-connected wood truss bridge. In: Baker, N.C.; Goodno, B.J., eds. *Proceedings, Structures Congress 12: papers presented at the structures congress '94; 1994 April 24–28; Atlanta, GA. New York, NY: American Society of Civil Engineers; Vol. 2: 1310–1315.*

- Usuki, S.; Ritter, M.A.** 1993. Field tests and development of stress-laminated wood deck bridges. *Bulletin of Structural Engineering*. 39 A(3): 1089–1100. (Printed in Japanese.)
- Wacker, J.P.; Ritter, M.A.** 1992. Field performance of timber bridges—1. Teal River stress-laminated deck bridge. Res. Pap. FPL–RP–515. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 19 p.
- Wacker, J.P.; Ritter, M.A.** 1995a. Field performance of timber bridges—3. Birchlog Run and Tumbling Rock Run stress-laminated deck bridges. Res. Pap. FPL–RP–538. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 11 p.
- Wacker, J.P.; Ritter, M.A.** 1995b. Field performance of timber bridges—4. Graves Crossing stress-laminated deck bridge. FPL–RP–539. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 17 p.
- Wacker, J.P.; Ritter, M.A.** 1995c. Field performance of stress-laminated timber bridges. *Wood Design Focus*. 6(2): 3–10.
- Wacker, J.P.; Ritter, M.A.; Conger, D.** 1996a. Field performance of timber bridges—8. Lynches Woods Park stress-laminated deck bridge. Res. Pap. FPL–RP–551. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 17 p.
- Wacker, J.P.; Seavey, R.; Erickson, R.** 1996b. Cold temperature effects on stress-laminated timber bridges. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. *Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI*. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 232–238.
- Wacker, J.P.; Ritter, M.A.; Stanfill–McMillan, K. [and others].** 1997. Field performance of timber bridges—11. Spearfish Creek stress-laminated box-beam bridge. Res. Pap. FPL–RP–556. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 17 p.
- Wacker, J.P.; Catherman, S.C.; Winnett, R.G.** 1998. Field performance of timber bridges—12. Christian Hollow stress-laminated box-beam bridge. Res. Pap. FPL–RP–560. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 17 p.
- Wang, J.Z.; De Groot, R.** 1996. Treatability and durability of heartwood. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. *Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI*. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 252–260.
- Wipf, T.J.; Ritter, M.A.; Duwadi, S.R.; Moody, R.C.** 1993. Development of six-year research needs assessment for timber transportation structures. Gen. Tech. Rep. FPL–GTR–74. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 44 p.
- Wipf, T.J.; Ritter, M.A.; Duwadi, S.R.** 1995. Dynamic evaluation of wood bridges. In: Sanayei, M., eds. *Restructuring: America and beyond: Proceedings of Structures Congress 13; 1995 April 2–5; Boston, MA*. New York: American Society of Civil Engineers; Vol. 1: 1–4.
- Wipf, T.J.; Ritter, M.A.; Wood, D.L.** 1996. Dynamic evaluation of timber bridges. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. *Proceedings, National conference on wood transportation structures; 1996 October 23–25; Madison, WI*. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 114–121.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE June, 1998		3. REPORT TYPE AND DATES COVERED	
4. TITLE AND SUBTITLE Research Accomplishments for Wood Transportation Structures Based on a National Research Needs Assessment				5. FUNDING NUMBERS	
6. AUTHOR(S) Michael A. Ritter Sheila Rimal Duwadi					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) USDA Forest Products Laboratory One Gifford Pinchot Drive Madison, WI 53705-2398				8. PERFORMING ORGANIZATION REPORT NUMBER FPL-GTR-105	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES					
12a. DISTRIBUTION / AVAILABILITY STATEMENT				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) In 1991, the USDA Forest Service, Forest Products Laboratory (FPL) and the Federal Highway Administration (FHWA) formed a joint cooperative research program for wood transportation structures. Development and execution of this program was based on a national assessment of research needs and priorities. In the 5 years since completion of the research needs assessment, significant research has been completed or is ongoing for wood transportation structures. This publication provides a summary of the research accomplishments of the joint FPL-FHWA research program for wood transportation structures.					
14. SUBJECT TERMS				15. NUMBER OF PAGES 30	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT		

