SUMMARY

An extensive U.S. research program to further develop wood utilization in transportation structures is currently in progress as a joint effort of the USDA Forest Service, Forest Products Laboratory and the U.S. Department of Transportation, Federal Highway Administration. This research is funded by U.S. legislation and involves cooperative research with universities, government agencies, and private industry. Within the program, research is divided into six areas: system development and design, lumber design properties, preservatives, alternate transportation system timber structures, inspection and rehabilitation, and technology and information transfer. This paper presents a brief summary of selected research program highlights within each of these areas.

INTRODUCTION

Research related to the use of wood as a material for transportation structures has increased substantially in the United States during the past 5 years. The primary reason for this increase has been U.S. legislation directed at furthering the development and utilization of wood as a material for bridges and other transportation structures. The first legislation in this area was the Timber Bridge Initiative (TBI), which was passed by the U.S. Congress in 1988. More recently, Congress passed the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA). In both cases, elements of the legislation were directed at establishing research and development programs to improve existing technology and develop new technology related to wood transportation systems and materials. Research leadership under the TBI has been delegated to the USDA Forest Service, Forest Products Laboratory (FPL). Under the ISTEA, research responsibility was assigned to the U.S. Department of Transportation, Federal Highway Administration (FHWA).

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To coordinate respective research activities, the FPL and FHWA initiated a joint research program involving wood utilization in transportation structures. By combining funding and other resources, a program was developed and implemented based on a comprehensive analysis of national research needs. Although timber bridges are the principal area of emphasis, the program was recently expanded to include other types of transportation structures, such as noise barriers, retaining walls, sign supports, and marine facilities. Research is accomplished as staff studies by FPL and FHWA engineers but is more commonly a cooperative research effort with universities, government agencies, and private industry. Additionally, technology and information transfer aimed at distributing research results is an integral part of the program.

RESEARCH PROJECT DESCRIPTIONS

Research activities under the joint FPL/FHWA program are divided into six general areas identified in the ISTEA legislation: System Development and Design, Lumber Design Properties, Preservatives, Alternate Transportation System Timber Structures, Inspection and Rehabilitation, and Technology and Information Transfer. A brief summary of selected research program highlights within each of these areas follows.
**National bridge monitoring program.** A bridge monitoring program is currently in progress to evaluate the field performance of more than 40 stress-laminated timber bridges including deck, T, and box designs constructed of sawn lumber, glued laminated (glulam) timber and structural composite lumber. These structures are located across the United States and include demonstration bridges as well as those built by local governments outside demonstration bridge programs. Monitoring activities for each bridge typically include a 2- to 3-year assessment of wood moisture content and bar force levels, two or more load tests, and intense visual inspections. Additional information may also be collected depending on specific site requirements. The information obtained from these activities is being used to develop improvements in design procedures, fabrication, and construction methodologies.

**Field evaluation of glulam bridge superstructures.** A study was initiated with the University of Alabama to evaluate the field performance of numerous glulam timber bridges. The bridges will consist of glulam girders with transverse glulam decks and will range in span from 4 m to more than 30 m. Monitoring will focus on dimensional stability, wood moisture content, general condition, and load test behavior. Currently, girders and deck panels for two bridges have been tested to determine modulus of elasticity values for future analytical modeling. Load tests are scheduled for summer, 1994. Results from this study will be used with analytical studies, laboratory testing, and additional field evaluations to develop recommendations for revised design criteria.

**Stress-laminated truss bridges using light-frame metal-plate-connected trusses.** A project is continuing with the University of Maine to develop stress-laminated truss bridges using light-frame metal-plate-connected trusses. The first phase, which is complete, involved an evaluation of cyclic moisture content, preservative treatment, and fatigue load effects on the connections. The second phase, which is currently in progress, addresses added concerns about connection durability under design environmental conditions. Specific research areas include possible connection corrosion, reduction in static load capacity as a result of cyclic loads and moisture conditions, and effects of cyclic moisture on joint fatigue capacity. The study will also collect preliminary information on the effects of fatigue and moisture on finite element design analogs that will be used in the truss bridge design phase. Results from this study, together with planned future research and field evaluations of experimental bridges, will form the basis for recommended design methods.

**Field evaluation of a timber bridge constructed with metal-plate-connected trusses.** A study was initiated with the University of Alabama to evaluate the field performance of the first timber bridge in the United States constructed of light-frame metal-plate-connected trusses. The bridge consists of two spans employing different truss configurations. The first span is constructed of a series of individual girders, which are constructed by bolting several trusses together to act as a unit, and is provided with a bolt-laminated lumber deck. To date, instrumentation has been installed, initial load testing is completed, and data are being collected on bar force and structural performance.

**Springs for maintaining bar force in stress-laminated bridges.** The FPL is continuing to evaluate the effectiveness of springs for maintaining bar force levels in stress-laminated timber bridges. Laboratory testing has been completed and springs have been installed on several bridges. The comparative field performance of bridge spans with springs compared to spans with no springs is being evaluated under the same environmental conditions. Results will be used to evaluate spring effectiveness and formulate recommendations on spring type, configuration, and placement for maintaining bar force.

**Long-span timber bridge systems using glulam timber.** A study is continuing with the University of Wisconsin to develop long-span stress-laminated cellular (box) bridge systems using glulam timber. The first phase of this study, which is complete, involved the evaluation of individual I and box sections to establish behavioral characteristics. The second phase, currently in progress, is continuing laboratory testing and will develop analytical methods for analyzing multi-cell box beam bridges. Based on research completed to date, it appears that stress-laminating alone is insufficient to maintain the composite action required for a thin-wall cellular system. Mechanical connections between the web and flange members are being evaluated. Recommended design guidelines will be formulated based on this research.

**Temperature reduction on interlaminar stress retention in stress-laminated bridges.** An FPL study is continuing to investigate the effect of temperature decreases on the prestress level in...
stress-laminated bridge decks. Laboratory testing is currently in progress on four deck specimens of various species and preservative treatments to assess temperature reduction effects at various prestress and moisture contents levels. Several bridges have also been instrumented with remote sensing equipment to determine the effects of temperature reduction under field conditions. A similar cooperative study is also in progress at the University of Minnesota where several stress-laminated decks constructed of Red Pine are being evaluated under controlled laboratory conditions to determine temperature effects for different temperature ranges and moisture content levels. Results of these studies will be combined to formulate design recommendations for stress-laminated bridges used in cold regions.

**Dynamic evaluation of timber bridges.** A project is continuing with Iowa State University to evaluate the dynamic behavior of timber bridges. The study includes superstructures constructed both of sawn lumber and glulam timber and will involve field and analytical evaluations. To date, dynamic load tests have been completed on nine stress-laminated timber decks and analysis is in progress. During the next 2 years, testing and analysis will be completed on glulam girder bridges, longitudinal glulam decks, spike-laminated lumber decks, and sawn stringer bridges. Results of this study will be used to formulate recommendations for design allowances related to dynamic effects.

**Load distribution in plank decks.** A study was initiated with the University of Michigan to determine the wheel load distribution criteria for transverse plank decks. Currently, thousands of plank decks are in service that do not meet current design criteria, yet continue to perform in an acceptable manner with no detectable structural problems. The study will involve both analytical and field work and will examine plank width, thickness, and span combinations to develop recommendations for revised design criteria. The study will also investigate load distribution to the sawn lumber stringers supporting the plank deck.

**Load distribution in glulam beam bridges.** A study is currently in progress with Gilham Engineering to analytically determine the load distribution to glulam girders that support a transverse glulam deck. Single- and multiple-lane bridges are currently being modeled over a range of bridge spans to determine live load distribution factors to interior and exterior girders. The results of this study will be used together with additional analytical work and laboratory and field testing to develop recommendations for revised design criteria.

**Portable wood bridge systems.** A study was initiated with Auburn University to develop wood bridges that are portable and suitable for use in temporary applications. These bridges are intended for use on roads where temporary access is required or where a bypass is necessary for the repair or replacement of existing structures. To date, preliminary design criteria have been formulated and initial designs are being developed. Analytical and laboratory testing will be completed on one or more designs, and a field structure will be constructed for further evaluation. At the conclusion of the study, a report and recommended design drawings will be available.

**Butt joints in stress-laminated decks.** A study is currently in progress at FPL to determine the effect of butt joints on the strength and stiffness of stress-laminated timber decks. A total of 12 decks will be tested with numerous butt joint frequencies and spacings to determine stiffness effects at various prestress levels. At the conclusion of the stiffness testing, each deck will be tested to failure to assess the butt joint effect on ultimate strength. Results from this study will be used to formulate design recommendations.

**Lumber Design Properties**

**Red Oak structural lumber properties.** A study at FPL is currently being completed to determine strength properties for Red Oak structural lumber in bending, tension and compression parallel to the grain. For visually graded lumber, all properties were found to exceed those expected based on present design properties. Relationships between different strength properties were found to be similar to those for softwoods. This data provided technical justification for the mechanical grading of Red Oak Machine Stress Rated (MSR) lumber. The results of this study were also the foundation for a demonstration research project that resulted in the first commercial grading of hardwood MSR lumber in the United States. This material was subsequently used to construct a stress-laminated timber bridge.

**Hardwood glulam timber.** Coordinated research projects with Pennsylvania State University and West Virginia University were completed to develop design information for Red Maple and Yellow Poplar structural glulam timber. For each species, 15 beams in each of 3 sizes were designed, manufactured, and evaluated to determine efficient grade combinations and associated strength properties. Results support design values comparable to those now used for
softwoods, such as Douglas-Fir and Southern Pine, provided portions of the lumber for the beams are mechanically graded. Results have been published as FPL research papers. The FPL scientists are participating in a task committee of the American Institute of Timber Construction, which has revised the hardwood glulam standard to obtain national acceptance of the results of the research for use in design. Additional cooperative research with Pennsylvania State University is underway to investigate Red Oak and the use of No. 3 grade Red Maple lumber.

**Shear design for glulam timber.** An FPL study to determine if a shear strength correlation exists for glulam timber is nearing completion. More than 200 Southern Pine and Douglas Fir beams have been tested and data have been analyzed. From this study, a relationship between shear strength and beam size was developed that used American Society for Testing and Materials (ASTM) shear block strength as a basis. This relationship is currently being balloted for inclusion into ASTM D245. Additionally, a publication that recommends a design procedure based on bending-shear correlation has been submitted for publication.

**Preservatives**

**Preservatives and water repellents for hardwood.** A study is continuing with Mississippi State University to evaluate the effectiveness of wood preservatives and water repellents on hardwood. Evaluations of the efficacy of chromated copper arsenate (CCA) alone, and CCA plus water repellents or stabilizers in hardwoods have been completed using small wood beams exposed in soil beds (fungus cellars). Small samples of Yellow Poplar, Red Oak, Red Maple, and Southern Pine (control) were treated with CCA and various treatments of water repellents and stabilizers. A report has been prepared and is currently being reviewed.

**Preservative treatment of red maple.** A cooperative study was initiated with the University of New York to investigate the treatability of red maple heartwood with generic representatives of osilborne and acidic or alkaline waterborne preservatives. Laboratory tests with small wood specimens indicate that some preservatives will be more effective in protecting red maple from attack by soft-rot fungi than chromated copper arsenate (CCA). This information will contribute to future consideration and utilization of this wood species in timber bridge applications.

**Stress-laminated bridge performance using CCA treated Southern Pine lumber.** A project is continuing to evaluate five stress-laminated deck bridges constructed of Southern Pine lumber treated with CCA. The bridges include both simple- and multiple-span continuous superstructures with various types of wearing surfaces, including asphalt pavement with a waterproof geotextile membrane. To date, field work has been completed and a report is being prepared. Results of this project will be used to formulate recommendations on the use of waterborne preservatives in stress-laminated bridge applications.

**Accelerated laboratory testing of new wood preservatives–ecosystem studies.** A project is continuing with Michigan Technological University to test 10 different wood preservatives for bridge applications. Accelerated testing using small wood beams are being conducted under laboratory and field conditions to determine efficacy for protecting various softwood and hardwood species commonly used for timber bridges. The specimens will be subjected to complexes of wood degrading fungi and to termites. The results of this study are necessary for the formulation of proposed treatment specifications for bridge members.

**Accelerated laboratory testing of new wood preservatives–pure culture studies.** A project is continuing with Oregon State University to test 16 different wood preservatives for bridge applications. Accelerated testing using small wood specimens will be conducted under laboratory conditions to determine efficacy for protecting seven softwood and eight hardwood species commonly used for timber bridges. The results of this study are necessary before field trials can be completed for code acceptance.

**Treatments and methods for field treating bridge members.** A study is continuing with Oregon State University to develop treatments and methods for field treating bridge members. This project will identify and/or develop equipment, preservative formulas and procedures for effectively treating field cuts, bore holes, and other breaks in preservative treatment encountered during bridge construction and maintenance operations. The project will result in a comprehensive users guide to remedial treatments for timber bridges.

**Wood preservative performance in stress-laminated bridges.** A project is continuing with Florida A&M/Florida State University to evaluate the effects of various wood preservatives and anchorage configurations on the dimensional stability of stress-laminated decks constructed of Southern Pine lumber. Seven different wood preservative formulations and three anchorage systems are being evaluated using full-scale stress-laminated decks. To date, the decks have been constructed and data are
Manual on wood preservatives. A project to develop a comprehensive manual on the use of wood preservatives for wood transportation structures is currently in progress. The manual will provide a practical background on wood deterioration processes, wood preservatives and environmental issues, and guidelines for specifying and using treated wood. In addition, information will be included for wood treaters regarding recommended processes and procedures for treating wood for transportation structure applications.

Alternate Transportation System Timber Structures

Crashworthy bridge rails; PL-1. A study was completed with the University of Nebraska and the American Institute of Timber Construction to develop crashworthy bridge rail systems for longitudinal timber decks. The following rail systems have been successfully tested at American Association of State Highway and Transportation Officials (AASHTO) PL-1:

- Glulam timber rail with curb
- Glulam timber rail without curb
- Steel rail without curb

Approach rail transition for a glulam timber rail to a steel approach rail

Several preliminary reports have been published. The final report is currently being prepared and will be available with recommended design drawings in the future.

Crashworthy bridge rails; PL-2. A project was initiated with the University of Nebraska to continue the previous program to develop crashworthy bridge rails for longitudinal deck timber bridges. This project will include the development and testing of the following rail systems at AASHTO PL-2:

- Glulam timber rail with curb
- Steel rail without curb

Approach rail transition for a glulam timber rail to a steel approach rail

To date, the glulam timber rail and the steel rail system have been successfully tested, data are being analyzed and reports and drawings are in progress. The remaining tests of the approach rail transition are scheduled for mid-1994. A final report and drawings will be available soon after the conclusion of the testing.

Bridge rails for low-volume roads. A study is continuing with the University of Nebraska and the USDA Forest Service to develop crash-tested bridge rails for low-volume roads. The study involves the development and testing of one curb system and two bridge rail systems. Evaluation of the curb system will be based on low-volume road criteria, which was developed as a part of the study to represent single-lane forest roads. Evaluation of the two railing systems will be based on the new U.S. criteria recently developed for low-volume roads. These evaluation levels are significantly less than those commonly used for highway bridge rail crash testing and will result in more realistic and economical bridge railing designs for low-volume road applications.

Timber bridge rail analysis and design. A study was initiated with the University of Nebraska that will develop a procedure to evaluate and design bridge rails for timber bridges. The procedure will be similar to that currently used for earthquake analysis and will be consistent with the philosophy and methodology of the load and resistance factor design (LRFD) limit states approach. Equivalent static forces will be developed for various impact conditions and railing types considering specific design details, geometric discontinuities, and retrofit options. This will provide bridge engineers with a rational and accurate method for designing new bridge rails and a reliable procedure evaluating existing railings for replacement or retrofitting.

Inspection and Rehabilitation

Timber bridge evaluation using stress wave technology. A project is continuing with Washington State University to develop guidelines for applying existing nondestructive testing technology for the in-place evaluation of timber bridges. The study will develop and present guidelines for equipment use and interpretive procedures for the evaluation of various bridge components based on field and laboratory research. Currently, field evaluation and laboratory work has been initiated, and stress-wave data for various species are being summarized.

In-place stiffness of stress-laminated timber decks constructed of saw lumber. A project is continuing at FPL to adapt existing nondestructive evaluation technology to develop equipment and simple procedures for determining the in-place stiffness of individual laminations within existing stress-laminated lumber bridges. This information will be used to evaluate field performance and assess structural integrity.

Technology and Information Transfer

AASHTO specification development for timber bridge design. A project is continuing to sponsor several meetings to develop proposed revisions to the AASHTO
Standard Specifications for Highway Bridges related to timber structures. To date, one meeting has been held involving representatives of the AASHTO Technical Committee on Timber Structures and the American Forest and Paper Association (AFPA) Timber Bridge Task Group. Proposals for revisions to the specifications have been identified and work has been initiated to develop and submit proposals to the AASHTO Highway Structures Subcommittee for adoption. A proposal for the inclusion of structural composite lumber in the AASHTO materials and design specifications will be presented in 1994.

Standard plans for Southern Pine bridges. A project is continuing with the Southern Forest Products Association and the University of Alabama to develop standard plans for Southern Pine bridge superstructures. The plans will include stress-laminated decks constructed of sawn lumber and glulam timber and solid sawn-stringer bridges with plank decks. Drawings are complete and are currently being reviewed.

Standard plans and specifications for timber bridge superstructures. A project is continuing with Laminated Concepts, Inc. to develop standard plans and specifications for timber bridge superstructures. The following superstructure types will be included in the project:
- Glulam beams with transverse glulam deck
- Longitudinal glulam deck
- Longitudinal stress-laminated deck
- Longitudinal spike-laminated deck
- Longitudinal nail-laminated deck
- Transverse nail-laminated deck
- Timber decks on steel beams

A study plan was completed and preparation of the designs is currently in progress. Final design drawings and specifications will be available as half-size drawings and on computer disk for use in computer-aided drafting systems.

FHWA demonstration timber bridge economics. A study was initiated to collect and analyze economic information on timber bridges constructed under the FHWA demonstration timber bridge program. To date, a form identifying the necessary data has been prepared and distributed to bridge owners. Data from demonstration bridges are being collected as it becomes available and will be published in the future.

National Bridge Inventory assessment. A study is continuing at FPL to complete an analysis and assessment of the National Bridge Inventory for timber bridges. Information from this study will provide insights into the longevity, distribution, and type of timber bridges built in the United States compared to bridges built of other materials. Additionally, the analysis will identify areas where improvements in inventory coding and bridge inspection methodology may be improved. To date, the inventory has been analyzed and a draft report has been prepared.

Interactive computer programs for wood bridge superstructures. A study is in progress with the University of Wyoming to develop computer programs for the design of the following wood bridge superstructures:
- Glulam beams with transverse glulam deck
- Longitudinal glulam deck
- Longitudinal stress-laminated deck
- Longitudinal spike-laminated deck
- Longitudinal nail-laminated deck

The programs will be developed using both allowable stress design and load and resistance factor design methods and will offer an interactive analysis, design, and load rating. Additionally, the programs will provide output information for computer aided design drawings that will be included with the programs.

PUBLICATIONS

A summary of selected publications resulting from research program activities follows.


