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Emerging Timber Bridge Technology in the United States

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ABSTRACT

Timber has been successfully used as a bridge material in the United States for hundreds of years. Historically, most timber bridges have been conventional beam or deck superstructures manufactured from softwood sawn lumber or glued laminated timber. Since 1988, two legislative acts have been passed by the U.S. Congress to establish national programs aimed at improving timber utilization in transportation structures. As a result, timber bridge research has increased, which is leading to significant technological advances. These advances have been well received, and many bridges utilizing new technology have been constructed. This paper briefly describes selected emerging timber bridge technology in the United States related to bridge materials, systems, and railings.

INTRODUCTION

Timber was the primary bridge material in the United States through the latter part of the 19th century. By the 1890's, the use of timber bridges began to decline and steel became the most widely used material for bridge construction. Technology in the steel industry developed rapidly in the early part of the 20th century, leading to the more expanded and economical use of steel bridges. Also during the early 20th century, use of reinforced concrete as a material for bridge decks increased, and in the 1940's, the introduction of prestressed concrete provided another popular option for bridge construction. During this period of rapid technological advancement of other bridge materials, progress in timber bridge development slowed. Although there were advances in the areas of wood fasteners and preservative treatments, it was not until the mid-1940's that a significant advancement in timber bridges occurred with the introduction of structural glued-laminated timber (glulam) as a bridge material. In the 1960's and 1970's, several new glulam bridge designs were developed, and glulam became a primary material for timber bridge construction.

Aside from gains in glulam technology, advances in timber bridge technology during the past 50 years have lagged significantly behind those of other materials. Despite the proven performance of timber bridges, and an expanding need for short and medium span bridges, little national emphasis was placed on timber bridge research and development compared to that for other bridge materials. This began to change when the U.S. Congress passed the Timber Bridge Initiative (TBI) in 1988 and the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991. Both of these legislative acts established national programs to improve the utilization of wood for transportation structures, with an emphasis on research and development of new technologies (Duwadi and Ritter 1997). This paper briefly describes emerging technology related to timber bridge materials, systems, and railings.

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BRIDGE MATERIALS

Construction materials can have a significant effect on the performance, longevity, and cost of timber bridges. Changes in the forest resource base and competitive demands for improved material utilization and performance have been the primary impetus for technological advances in timber bridge materials. These advances have focused on traditional materials such as sawn lumber and glulam, but have also extended to relatively new materials such as structural composite lumber.

Sawn Lumber

Timber bridges in the United States have historically been constructed from two primary softwoods: Douglas–fir and Southem Pine. Although many other species are plentiful, their use in bridge applications has been limited. In the late 1980's, a directed effort under the TBI furthered the use of underutilized, non-traditional secondary softwoods and hardwoods. The primary barriers to this effort centered on design values and material availability. For the most part, design values for secondary softwoods were available to designers but published values for hardwoods were very limited. In addition, lumber suppliers were hesitant to produce graded material in standard structural sizes. To resolve these issues, research over the past decade has developed hardwood design values and improved methods of hardwood lumber grading (Green *et al.* 1994; 1996). There has also been a significant effort to educate lumber producers and designers and encourage the use of non-traditional wood species. As a result, over 200 bridges have been built from hardwood or secondary softwood lumber. Primary species have included oak, maple, beech, cottonwood, ponderosa pine, and eastern hemlock. Generally, bridge materials produced from the secondary softwoods have been economically competitive because alternative uses for the material have been of relatively low value. For hardwoods, however, many alternate material uses such as furniture and millwork are of high value, and material costs for hardwood lumber have significantly exceeded those of alternative softwood species commonly used for bridge construction. Experience has shown that the most economical hardwood lumber far bridge applications is that cut from the center of logs where lower quality material is typically obtained for pallet construction and railroad crossties. Thus, the key to increased hardwood utilization in bridges is to identify those bridge types and applications where lower quality material is acceptable.

Glulam

The resource base for traditional commercial lumber species bas changed significantly over the past decade. As the percentage of lumber obtained from second growth forests and non-traditional species increases, the availability of large sawn lumber structural members decreases. One popular option for bridge construction has been the use of glulam, where large structural members can be manufactured from nominal 50-mm-thick lumber. Glulam can be manufactured from any softwood or hardwood species provided it meets necessary strength and stiffness requirements. In practice, most glulam used for bridges in the United States has historically been manufactured from Douglas-fir or Southern Pine. As the available wood resource changes, and emphasis on using non-traditional wood species increases, there has been growing interest in developing new glulam layups for both hardwood and softwood species. Over the past 6 years, efficient glulam beam layups have been developed using red maple, red oak, and yellow poplar (Manbeck *et al.* 1993; Shaffer *et al.* 1991; Moody *et al.* 1993). As a result of this work, hardwood glulam beams with properties comparable to those obtained for Douglas-fir and Southern Pine are now attainable and several hardwood glulam bridges have been built (Hernandez *et al.* 1996). Efforts to develop glulam from secondary softwood species have also been successful, and layups using red pine have been used for bridge construction (Wacker and Ritter 1992). Other projects using secondary species, such as cottonwood and eastern hemlock, are planned.

A primary obstacle to more widespread use of hardwood glulam in bridges has been the cost of hardwood lumbar. The hardwood glulam bridges constructed to date have been substantially more expensive than comparable bridges manufactured from primary softwood species. As previously discussed for hardwood lumber, the economic future of hardwoods in glulam depends on applications where more economical, low quality material can be used. Two potential applications that are currently being investigated include mixed species beams and glulam deck panels. In mixed species beams, low quality hardwood can be used for the beam core material with high quality Southern Pine in the tension and compression zones. For glulam deck panels, relatively low quality hardwood lumber can be laminated into glulam deck panels measuring 130–180 mm thick. Bridges incorporating these options using red maple lumber are planned in 1998.

In addition to glulam manufactured from hardwood and secondary softwood species, a significant effort is currently underway to develpo glulam beams using nonwood composites. In most instances, glulam beam bending strength is controlled by the tensile strength of the lumber or the end joints on the tension side of the beam. The potential for increasing the bending strength by reinforcing the tension side has been evaluated by many investigators during the past 30 years using a variety of materials. Recent developments in fiber-reinforced plastic (FRP) suggest that this big high performance material offers the possibility of being easily attached to wood. Forming a composite by using a small amount of FRP offers the potential for significantly increasing the strength of beams, but will likely have a limited effect on stiffness. To date, numerous bridges have been constructed using glulam beams with FRP plates bonded in the beam tension zone (Tingley *et al.* 1996). Research has also been completed to prestress reinforcing fibers directly in the glue line between lumber laminations (Galloway *et al.* 1996). Reinforced glulam beams of this type have the best chance of showing economic advantages in applications where either (1) bending strength controls the design, (2) it is critical to minimize beam depth, or (3) the beams are part of a composite structure where the added strength provides substantial benefits. It also appears that the greatest economic gain will be in glulam manufactured with low strength species. Beyond these applications, the economics of using reinforced glulam beams must be compared with the use of traditional softwood beams that are manufactured somewhat deeper to achieve the required strength and stiffness.

Structural Composite Lumber

Structural composite lumber (SCL) is an engineered wood product that bas been used in building construction for over 20 years but has only recently been introduced for bridge construction. The two types of SCL used for bridges are laminated veneer lumber and parallel strand lumber. Laminated veneer lumber consists of thin sheets of veneer that are glued together with the grain direction oriented along the length of the member. Parallel strand lumber is manufactured of small wood veneer or strand elements that are glued together with the grain parallel. Both types of SCL are highly engineered wood products that provide design values comparable to or slightly higher than those for glulam. One obstacle to the widespread use of SCL for bridge applications has been the lack of SCL design values in the American Association of State Highway and Transportation Officials (AASHTO) *Standard Specifications for Highway Bridges.* This was subsequently resolved, and design values for SCL were included in the 1996 specifications (AASHTO 1996).

BRIDGE SYSTEMS

Most timber bridges built in the United States have historically been conventional beam or deck superstructures constructed of sawn lumber or glued-laminated timber. Over the past decade, emphasis has been placed on developing new designs which allow for improved utilization of hardwood and secondary softwood species. Emphasis has also been placed on evaluating the more traditional timber bridge types to improve design efficiency related to structural and serviceability performance, economics, and longevity. A brief discussion of emerging technology related to both new and traditional designs follows.

New Designs

The majority of research related to new timber bridge systems has focused on the concept of stress laminating. Stress-Laminated decks are constructed by placing wood laminations on edge and stressing the laminations together on the wide face with high strength steel bars (Ritter 1990). The compression serves to transfer load between the laminations, causing the deck to act as a large orthotropic wood plate. Stress-laminated deck bridges were first used in Ontario, Canada, and were introduced in the United States in the late 1980's. The concept was well received because bridges could be built with local labor, and the design allowed for butt joints in the lumber laminations which permitted the use of relatively short length lumber to construct bridges with spans up to 11 m. As a result, more than 400 stress-laminated sawn lumber bridges have been built and a guide specification for design was published by AASHTO (1991). Work is currently concluding to define more accurate wheel load distribution criteria than that currently given in the AASHTO specifications and to quantify the effect of butt joints on the strength and stiffness of stress-laminated decks at various levels of prestress.

Extensive field evaluations of over 30 stress-laminated sawn lumber bridges for periods up to 6 years in-service indicate that bridge performance has generally been good, but tension force loss in the steel bars has often been higher than that originally anticipated from Canadian experience (Ritter *et al.* 1995a). In many cases, bar retensioning is required within the first 2 years after construction, and periodically thereafter. One factor in the loss of bar force has been the relatively small elongation in the steel bars when the initial tension force is applied. With little bar elongation, a relatively minor decrease in bar length can result in a substantial loss in bar force. Thus, shrinkage of the bridge deck width due to moisture loss or stress relaxation in the lumber laminations can result in significant bar force loss. To minimize this effect, alternative stressing elements which provide increased elongation are being evaluated. Two promising options include steel prestressing strand and FRP bars (Dagher *et al.* 1997). Replacement of steel bars with these alternative materials will likely result in a decrease in force loss and improved economy since both are potentially less expensive than the galvanized steel bars currently used.

The concept of stress-laminating decks has also been expanded to include the use glulam, rather than sawn lumber, as deck laminations. This came about in response to a need for longer spans and deeper decks than can be economically provided by sawn lumber. Using this approach, glulam beams of variable width are stressed together to form the bridge deck (Figure 1). The first known example of this type of construction was the Teal River bridge (Wacker and Ritter 1992). Since construction of this bridge, several similar bridges have been built, some with spans exceeding 15 m. Because glulam allows for deeper sections, longer bridge spans are possible. Additionally, glulam can be manufactured to be continuous over the bridge length and butt joints are not required. One of the most noteworthy advantages of glulam use has been the force retention in the stressing bars. Because glulam is dry when installed, bar force loss due to lamination shrinkage from stress relaxation and moisture loss has been very small. Overall, these glulam stress-laminated bridges have demonstrated excellent performance.

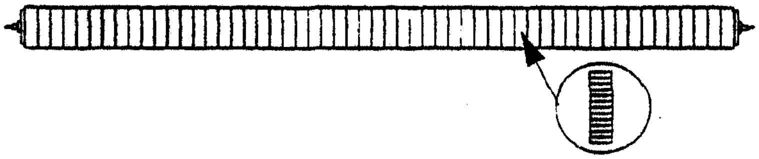

Figure 1: End view cross-section of a stress-laminated deck constructed using glulam beams.

Because the clear span of stress-laminated decks is limited by design and economical limitations on the bridge depth, other options have been investigated to provide longer clear spans. Two types of experimental bridges that are currently being evaluated are T- and box-beam bridges (Figure 2). T-beam bridges are typically constructed using vertical glulam webs with flanges constructed of sawn lumber. The composite action between the flange and web is developed through friction by compressing the section with stressing bars through the flanges and webs. The box section is basically the same as the T section, but a bottom flange and stressing bars are added to create a greater moment of inertia.

To date, over 50 stress-laminated T- and box-beam bridges have been constructed. The longest structure is a 27-m span stress-laminated T-beam bridge, which was built in Arkansas in 1993. Field performance of many of these bridges is currently being evaluated and several publications are available (Wacker *et al.* 1997). In general, the costs of T- and box-beam bridges have exceeded expectations and a conventional glulam girder bridge typically provides a more economical option. As with stress-laminated decks, there bas also been higher than expected bar force loss. This is more critical in the T- and box beam configurations because slip between the flange and web can occur at a higher bar force than slip in a stress-laminated deck. The new alternatives to replace steel bars for stress-laminated decks (previously discussed) should also help to reduce bar force loss in stress-laminated T- and box-beam bridges.

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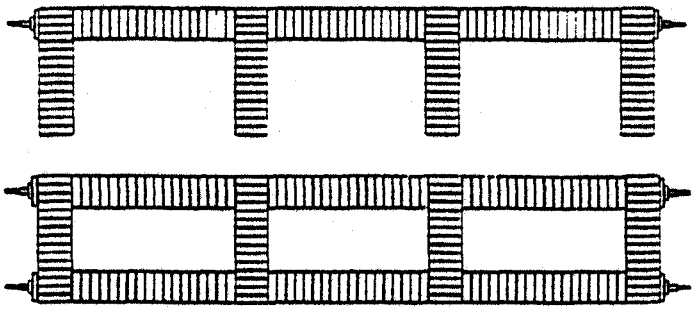

Figure 2: End view cross-sections of a stress-laminated T-beam bridge (top) and a stress-laminated box-beam bridge (bottom).

The concept of stress-laminated T- beam bridges has also been extended to SCL. Unlike the T-beam bridges previously discussed, Which use glulam webs with sawn lumber flanges, SCL T-beam bridges are constructed using integral SCL, T-sections that are manufactured in one piece. The T-sections are placed side-by-side and are stress-laminated through the top flange (Figure 3). For improved dimensional stability, SCL box sections are typically placed along the bridge edge. To date, more than 35 of these bridges have been constructed with spans of 7.3 to 15.2 m. The first approximately 20 bridges were constructed of laminated veneer lumber, but more recent structures have used the more economical parallel strand lumber. Bridges constructed of both types of SCL are demonstrating good field performance and bar force retention has not been a problem (Ritter *et al.* 1996). Thus, the system represents another viable option both for new construction and bridge replacesnent.

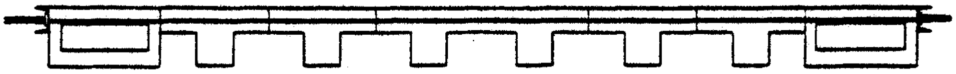

Figure 3: End view cross-section of a stress-laminated SCL T-beam bridge.

Traditional Bridges

in addition to developing technology for new timber bridge designs, considerable research has been directed at refining and improving more traditional timber bridge designs. Primary efforts have focused on the behavior of timber bridges under dynamic truck loading and the distribution of vehicle wheel loads. Little previous work has been completed to assess the dynamic effect of vehicles on timber highway bridges. Current AASHTO allowable stress design specifications (AASHTO 1996) do not require consideration of a dynamic load allowance or “impact” factor for timber bridges. However, the more recent AASHTO Load and Resistance Factor Design (LRFD) Specification (AASHTO 1994) require that timber bridge designs include a dynamic loading factor equal to 50% of that required for steel and concrete bridges, or 16.5%. For both specifications, it is not possible to determine the technical basis for these requirements. To alleviate the uncertainty surrounding dynamic loading for timber bridges, an extensive research program was initiated. Through a comprehensive program of field testing and analytical modeling, recommendations for a dynamic load allowance for timber bridges are currently being developed for glulam girder bridges with transverse glulam deck panels, longitudinal glulam decks, and stress-laminated decks (Wipf *et al.* 1995, 1996).

In addition to the dynamic effect on timber bridges, field testing and analytical work are also in progress to determine the distribution of vehicle live loads on traditional girder/stringer bridges and longitudinal timber decks. Currently, most timber bridge load distribution design criteria are based on simplified relationships such as the “lever rule” where the bridge deck is assumed to act as a simple span between supporting members. By field testing bridges and formulating accurate analytical models, revised load distribution criteria will be developed which will more accurately reflect actual bridge behavior for both strength and serviceability criteria. From a strength standpoint, this will allow for improved reliability in timber bridge designs and potentially improve economics. When serviceability is considered, more accurate methods for predicting global and localized deflections will help improve asphalt wearing surface performance and longevity, especially on panelized bridge deck systems.

BRIDGE RAILING

The design of bridge railing systems in the United States has historically been based on static-load design criteria given in the AASHTO *Standard Specifications for Highway Bridges.* In the past decade, full-scale vehicle crash testing has been recognized as a more appropriate and reliable method of evaluating bridge railing acceptability. In 1989, AASHTO published *Guide Specifications for Bridge Railings,* which gives the recommendations and procedures to evaluate bridge railings by full-scale vehicle crash testing (AASHTO 1989). In 1993, the National Cooperative Highway Research Program (NCHRP) published Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features,* which provides criteria for evaluating longitudinal barriers (Ross *et al.* 1993). In both cases, a primary concept is that bridge railing performance needs differ greatly from site to site and railing designs and costs should match site needs. Thus, recommended requirements for railing testing are based on different performance levels. The relationship between the railing performance level and requirements for a specific bridge depend on a number of factors, such as the type of roadway, design speed, average daily traffic, and percentage of trucks in the traffic mix.

Since the early 1990's, there has been increasing emphasis on full-scale crash testing as a means of evaluating railing performance. For timber bridges to be viable and competitive with bridges of other materials, a range of crash-tested bridge railings for different wood bridge types is required. Based on this need, national emphasis was placed on developing a number of crash-tested railings at different performance levels and a three-phase program was developed. Phase 1 focused on railings for longitudinal deck bridges constructed of glulam, spike-laminated lumber, or stress-laminated lumber that are 252 mm or greater in thickness (Faller *et al.* 1996). This phase was completed in 1995 and plans for five crash tested bridge railings were published (Ritter *et al.* 1995b). Phase 2 is currently concluding and includes four bridge railings intended specifically for timber bridges on low volume roads. Phase 3 is in progress to develop four crashworthy bridge railings for transverse glulam decks 130 mm or greater in thickness. Incidental to this testing, several timber bridge railings will also be adapted for use on concrete bridge decks.

CONCLUDING REMARKS

New technology related to timber bridges has increased dramatically in the United States over the past decade. As a result, advances in timber bridge materials, systems, and railings have contributed to a renewed interest in timber as a bridge material. As emerging technology continues to develop, advances such as these will help to improve the economics, performance, and longevity of timber bridges and help put timber on the same technological basis as other bridge materials.

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