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Innovations in Glulam Timber Bridge Design

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Abstract

Structural glued laminated timber has been successfully used as a bridge material in the United States for more than 50 years. Until the late 1980s, the majority of these bridges were conventional girder or deck superstructures manufactured from softwood lumber species. Recently, applications employing glued laminated timber have been expanded to include alternative wood species and new designs utilizing the concept of stress-laminating. Additionally, current research on the composite materials using glulam may lead to future applications for timber bridges.

Introduction

Structural glued laminated timber (glulam) is an engineered, stress-rated product of a timber-laminating plant. It consists of selected and prepared lumber laminations that are bonded together on their wide faces with structural adhesives. Glulam has been successfully used as a structural material in Europe since the late 1800s, In the United States, it has been used in buildings since approximately 1935 and in highway bridges since the early 1940s. An important feature of glulam is that it is an

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engineered wood product rather than a product made simply by gluing wood pieces together. Additionally, the use of waterproof adhesives results in durable gluelines that are suitable for extended service in exposed bridge applications.

Glulam is a versatile material that provides several distinct advantages for bridge construction. Because it is a manufactured product, glulam can be produced in a wide range of shapes to virtually any size. Most glulam used in bridges involves straight members, but curved or tapered members are used in some applications. In general, glulam has reduced variability and increased strength compared to sawn lumber because the laminating process disperses strength-reducing characteristics, such as knots, throughout the member. Glulam also provides better dimensional stability because it is manufactured from dry lumber. For beam-type applications, glulam is manufactured using selective lamination placement so that higher quality material can be placed in the top and bottom of the beam, where bending stress is greatest, and lower quality material can be placed in the inner layers of the beam, where bending stress is lowest. This practice helps to extend the available lumber resource and improves the economy of the final glulam product.

The majority of the glulam bridges built in the United States have been conventional girder-deck or longitudinal deck superstructures (Ritter, 1990). Since the late 1980s there has been much activity to extend the use of glulam for bridge applications *into* innovative areas. This paper will briefly describe several of these areas including the use of altemative species for glulam manufacture, applications employing glulam for stress-laminated decks and T and box sections, and the utilization of glulam in composite applications with other materials.

Alternative Species

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 has historically been manufactured from Douglas Fir-Larch and Southern Pine. As the available wood resource changes, and with increased emphasis on using underutilized local wood species, there has been increasing interest in developing new glulam layups for both hardwood and softwood species. Over the past 4 years, most work on alternative species for glulam has centered on the utilization of hardwood lumber, although several secondary softwood species have also been used.

Research completed at Pennsylvania State University, West Virginia University (WVU) and the USDA Forest Service, Forest Products Laboratory (FPL) was directed at developing glulam manufactured from red maple, red oak and yellow poplar (Manbeck, et al., 1993; Shaffer, et rd., 1991; Moody, et al., 1993). Although a hardwood glulam standard has been available for many years, the standard neither uses structural lumber grades nor provides for efficient use of various grades for beam applications. Recent results for red maple, red oak and yellow poplar indicate that bending design values comparable to those for Douglas Fir-Larch and Southern Pine can be attained for these species.

In addition to developing hardwood glulam, efforts to develop glulam from secondary softwood species have also been sucessful. A project in Wisconsin using both red pine and Southern Pine in glulam resulted in the construction of a stress-laminated bridge in 1989(Wacker and Ritter, 1992). This further led to the design and construction of a stress-laminated bridge using glulam manufactured exclusively from red pine lumber. Other projects using secondary softwoods, such as eastern hemlock, are planned for the future.

Stress-Laminated Decks

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 between the laminations serves to transfer load between the laminations, causing the deck to act as a large plate of wood. Stress-laminated bridges were first used in Canada and were introduced in the United States in the late 1980s. Since that time, over 150 bridges have been built using sawn lumber laminations, and a guide specification for design of these bridges has been published by the American Association of State Highway and Transportation Officials (AASHTO, 1991).

In 1989, the concept of stress-laminating decks was expanded to use glulam beams, rather than sawn lumber, as deck laminations (Figure 1). This came about *in* response to a need for greater depth than can be economically provided by *sawn* lumber. Using this approach, glulam beams of variable width, which are continuous between supports, are stressed together to form the bridge deck. The first known example of this type of construction was the Teal River bridge constructed in Wisconsin (Wacker and Ritter, 1992). Since construction of this bridge, several other structures have been built, including a second bridge in Wisconsin and one in West Virginia.

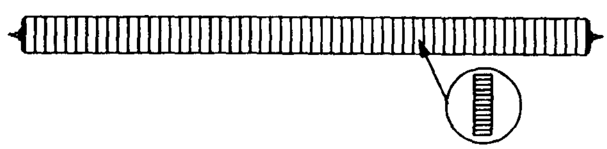

Figure 1. End view cross-section of a stress-laminated deck constructed using glulam beams as the deck

Bridges using glulam in stress-laminated deck applications have demonstrated excellent performance. Because glulam allows for deeper sections, longer bridge spans are possible. Additionally, the glulam can be manufactured to be continuous over the bridge length and butt joints, which can reduce the bridge strength and serviceability, are **not required. One** of the most noteworthy advantages of glulam use has been the force retention in the stressing bars. Because the glulam is dry when installed, the laminations slowly absorb moisture and the deck swells slightly as it moves toward an equilibrium moisture content. As a result, this swelling offsets force loss due to stress relaxation in the wood and the net loss in bar force is minimal.

T- and Box-Beam Bridges

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 have been successfully used 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 the web is developed through friction by stress-laminating the section with stressing bars through the flanges and webs. The box section is basically the same as the T section, but flanges and stressing bars are added to create a higher moment of inertia.

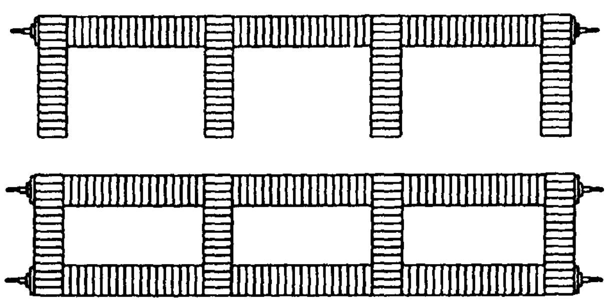

Figure 2. End view cross-sections of a stress-laminated T-beam bridge (top) and a stress-laminated box-beam bridge (bottom)

The concept of stress-laminated T- and box-beam bridges has been well received and more than 30 bridges have been built over the past 3 years. The longest span structure is an 87-foot (27-m) span stress-laminated T-beam bridge, which was built in Arkansas in 1993. Most research work regarding these bridges was completed at West Virginia University, in cooperation with the Federal Highway Administration (FHWA) and FPL, and used a modular construction approach (Barger, et al., 1993; Davalos, et al., 1993). In addition to continued research on stress-laminated T- and box-beam bridges using glulam and sawn lumber, research is underway at the University of Wisconsin, in cooperation with the FPL and FHWA, to develop systems constructed completely from glulam panels (Oliva and Rammer, 1993).

Research and field evaluation are continuing on the structural performance of these systems. Draft specifications for the design and construction of stress-laminated T- and box-beam bridges are currently being developed for submission to AASHTO.

Glulam Composites

In most instances, the bending strength of glulam 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 of glulam by reinforcing the tension side has been evaluated by marry investigators during the past 30 years using a variety of materials. Recent developments in fiber-reinforced plastic (FRP) suggest that this 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 limited effect on stiffness.

Recent work has been completed using various types of fibers in FRP to reinforce glulam (Tingley, 1990). At a poster session at the 1993 Forest Products Society Meeting in Clearwater, Florida, Tingley and other researchers from Oregon State University reported favorable results by reinforcing the tension zone of glulam using FRP with high-strength fibers. Cooperative research is underway between West Virginia University and FPL to investigate the usc of FRP bonded to either the tension side only or to both the tension and compression sides of beams. These research efforts could soon lead to the construction of experimental bridges using the composites. Reinforced beams 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.

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