In Situ Performance of Stress-Laminated Timber Bridge Decks

James A. Kainz, **General Engineer**, James P. Wacke,. **General Engineer,** Michael A. Ritter, **Research Engineer**
U.S. Department of Agriculture, Forest Service, Forest Products Laboratory
One Gifford Pinchot Drive, Madison, WI 53705 USA

Introduction

The National Bridge Inventory has listed as many as 50% of all bridges in the United States as functionally obsolete or structurally deficient. Bridge condition is determined by bi-annual inspection performed by local engineers and submitted to the Federal Highway Administration (FHWA) for inclusion in the National Bridge Inventory. The inspection requires the engineer to know the critical elements of many bridge types constructed of various materials.

Many types of timber bridges are in use on the highway system. One relatively new type is the stress-laminated deck bridge. A stress-laminated timber deck bridge consists of a series of wood laminations that are set on edge and compressed together using high-strength steel bars (Fig. 1). The tensile force introduced into the bars, which typically ranges from 111 to 356 kN, compresses the laminations together so that the resulting deck. acts as a solid wood plate. Stress-laminated wood bridges were developed in Ontario, Canada, as a means of rehabilitating nail-laminated lumber decks that were delaminating due to cyclic loading and wood moisture content variations [1,2]. In the 1980s, the stress-laminated concept was adapted to new construction due to increased performance benefits compared with traditional nail-laminated bridges. Many stress-laminated decks have been built throughout the United States, using various materials and species.

The performance of a stress-laminated bridge is largely dependent upon the retention of compressive force between the wood laminations. The lamination compressive force is a result of the tensile bar force in the steel bars. The bar force is altered over time by the relaxation of the wood when it is compressed. This relaxation can increase with higher moisture content laminations. Bar forces are also altered due to dimensional changes in the wood laminations.

Since the stress-laminated timber bridge was a relatively new system, a nationwide bridge monitoring program was established by the USDA Forest Service, Forest Products Laboratory (FPL), in 1990 [3] and expanded in 1992 to include a cooperative program with the FHWA. The purpose of this program is to monitor and evaluate bridge performance and behavior to develop, confirm, or improve methods of design, fabrication, and construction. This paper presents a review of the methods and a summary of the results of the in situ performance of stress-laminated timber bridges.

Methods Review

The in-situ performance of a typical stress-laminated timber deck is measured by monitoring, which includes collecting data on stressing bar force, wood moisture content, temperature, static load testing, and inspection of the bridge. Each of these data sets provides a unique characteristic of the performance of the bridge.

Stressing Bar Force

Due to the material properties of the wood laminations and the configuration of the stress-laminated system, the inter-laminar compression in the deck will diminish over time due to stress-relaxation [2]. A stress-laminated bridge requires a minimum amount of inter-laminar compression to maintain bending performance in the transverse direction. Stressing bar force is an indicator of the interlaminar compression performance of the bridge. Therefore, monitoring the stressing bar force is vital to understanding bridge performance. The stressing bar force is monitored by installing load cells on several bars of the bridge. The load ceils were developed by the Forest Products Laboratory [4] and have undergone design and manufacturing improvements that improve their long-term monitoring performance. The load cells measure changes in strain in the steel bar. The load cell readings are recorded manually with **a** portable strain indicator (Fig. 2) or automatically through a remote data acquisition system [5]. The measured strain is converted to an equivalent bar force by using a calibration obtained in laboratory testing. Load cell readings are normally taken on a monthly basis using the manual method, while the automatic method can obtain readings as often as once every hour.

Moisture Content

The performance of wood structures is affected by moisture content. Excessive moisture content can have detrimental effects on wood material properties that can contribute to decay, increased creep, strength loss, and dimensional change (when below fiber saturation) [6]. If a stress-laminated timber bridge is constructed with high moisture content laminations, performance problems can occur, consisting of increased bar force loss over time due to dimensional instability and increased stress-relaxation of the wood laminations. Moisture content determination can help predict the performance of stress-laminated bridges. Moisture content is measured manually by electrical resistance moisture meters (Fig. 3) or by removing a “core” from the wood laminations.

In the electrical resistance method, two pins are inserted into the lumber and the electrical resistance between the pins is recorded. A moisture content value is obtained based on empirical data. A moisture content value from the core method is obtained by weight of water of the wet specimen compared with the dry specimen using

$$MC = \left(\frac{Weight_{wet} - Weight_{dry}}{Weight_{dry}} \right) 100$$

Each manual method requires a site visit to obtain a reading. Usually, moisture content changes occur slowly in a stress-laminated bridge because wood laminations are compressed tightly together which allows limited exposure to the environment. Automatic methods are available for moisture measurements but have a limited life due to moisture swelling and shrinkage at the sensor location. New methods for noninvasive moisture content techniques are presently under development.

Temperature Effects

Temperature affects all structures, and thermal considerations are included in the design of many concrete and steel bridges [7]. Thermal design factors are usually not included in the design of timber bridges since temperature has a negligible affect on members which are oriented parallel to grain (which is usually in the span direction). However, the bar force in a stress-laminated timber bridge is affected by temperature change due to the orientation of the wood laminations. Temperature changes are monitored in stress-laminated decks through thermocouples attached to a remote data acquisition system. Usually several thermocouples are inserted into the deck to measure internal deck temperature. Testing has shown that there is a temperature effect on bar force in stress-laminated decks that results in a bar force loss when temperatures drop below the freezing point of water [8]. However, these bar force changes are recoverable and the magnitude of the bar force is dependent upon the initial moisture content of the wood laminations.

Static Load Tests

Static load tests provide valuable information about the performance of a stress-laminated bridge. These tests are completed by placing one or two trucks on the bridge (depending whether the bridge is one or two lanes) and using a surveyor's level to read the resulting deflections on calibrated rules hung from the bridge's underside (Fig. 4). New methods are currently under refinement using displacement transducers to measure bridge deflections. The increased speed and accuracy of the displacement transducers allows improved testing during static and dynamic load testing.

A stress-wave technique is currently under evaluation to determine the in-place stiffness of stress-laminated decks [9]. The resulting data can then be used for input in modeling programs to predict the deflection of the bridge under loading. These deflections can supply insight into the performance of the bridge when compared with the deflections obtained during static load testing.

Bridge Inspections

Bridge inspections of stress-laminated timber bridges highlight several areas. The visual inspection of the wearing surface, bridge camber, wood components, and steel bars all give insight as to the overall performance of the bridge. Cracks in the wearing surface may be a result of excessive deflection, insufficient bar force, or inter-laminar slip. Loss of bridge camber is usually a result of excessive creep in the bridge laminations. Crushing, checks, or splits on the wood members are indicators of high moisture content conditions or uneven drying. In addition, areas with no preservative due to field cutting or drilling can lead to premature deterioration. Corrosion on the steel bars indicates improper galvanizing and could lead to future failures. In addition to these Visual techniques, several nondestructive methods are under evaluation to determine the condition of stress-laminated bridges in place. These methods consist of a global assessment technique, such as dynamic response combined with local techniques such as acousto-ultrasonics and stress-wave. These nondestructive methods will improve inspection by allowing the inspector to evaluate the bridge beyond the wood surface.

Results Review

Since its inception, the FPL/FHWA monitoring program has examined more than 50 bridges. With few exceptions, the general performance of these bridges has been acceptable [10-13]. When problems were encountered, they were usually a result of high moisture content and included excessive bar force loss, creep, and increased wood checking [14]. These problems were mostly serviceability in nature, because the monitoring methods used were able to detect low bar force, which allowed bar retensioning before structural problems occurred.

The increased bar force loss was a result of dimensional change in the wood laminations as the members dried. It has also has been shown that moisture content can be a contributor to stress-relaxation loss in the wood. Along with transverse stress-relaxation loss in the wood, vertical creep was a concern because several of the bridges began to sag during the monitoring period. Finally, wood checking and/or splitting is a result of uneven drying in large members and can increase the chances of early decay by opening up the preservative envelope. Although no decay was detected, several bridges had large checks and splits develop on the rail posts and rail tops.

Concluding Remarks

The monitoring methods described herein have proven to be a reliable and accurate means to measure the performance of stress-laminated bridges. The results from the FPL/FHWA monitoring program have been reported in a series of publications that are currently available through Forest Products Laboratory. Additional information on the FPL/FHWA monitoring program, can be found on the FPL website at www.fpl.fs.fed.us/wit/.

References

1. Taylor, R.J.; Csagoly, P.F. 1979. Transverse post-tensioning of longitudinally laminated timber bridge decks. Ministry of Transportation and Communications, Downsview, Ontario, Canada.
2. Taylor, R.J.; Batchelor, B.; Van Dalen, K. 1983. Prestressed wood bridges. SRR-83-01. Ministry of Transportation and Communications, Downsview, Ontario, Canada.
3. USDA Forest Service. The Timber Bridge Initiative: Fiscal Year 1995 Status Report. Radnor, PA: U.S. Department of Agriculture, Forest Service, State and Private Forestry, Northeastern Area, 1995.
4. Ritter, M.A.; Geske, E.A.; McCutcheon, W.J.; Moody, R.C.; Wacker, J.P.; Mason, L.E. 1991. 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.
5. Ritter, M.A.; Wacker, J.P.; Duwadi, S.R. 1995. Field performance of stress-laminated timber bridges on low-volume roads. In: Proceedings of the 6th International conference on low-volume roads; 1995 June 25-29; Minneapolis, MN. Washington, DC: National Academy Press: 347-357; Vol. 2.
6. Forest Products Laboratory. Wood Handbook: Wood as an engineering material. Agric. Handb. 72. Washington, DC: U.S. Department of Agriculture; rev. 1987. 466 p.
7. Standard specifications for highway bridges 14th ed. Washington, DC: American Association of State Highway and Transportation Officials. 1989.
8. Wacker, J.P.; Seavey, R.; Erickson, R. 1996. Cold temperature effects on stress-laminated timber bridges. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., ed(s). 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.
9. 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., ed(s). 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.
10. 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. 17p.
11. 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.
12. 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.
13. Wacker, J.P.; Ritter, M.A.; Conger, D. 1996. 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.
14. Kainz, J.A.; Wacker, J.P.; Nelson, M. 1996. 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.

Proceedings

of the

SEM Spring Conference on Experimental and Applied Mechanics

and

Experimental/Numerical Mechanics in Electronic Packaging III

Houston, Texas

June 1-3, 1998

Published by the Society for Experimental Mechanics, Inc.