

FINAL REPORT

Evaluation of Stress-Laminated Wood T-Beam and Box-Beam Bridge Superstructures

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Abstract

Early testing and modeling of stress-laminated T-beam and Box-beam timber bridge superstructures indicated that bridges built using this technology appeared to have promising structural behavior. However, during further field testing, questions arose about the performance and cost of the bridge systems. This project assembled a literature review on research and performance studies for stress-laminated T-beam and Box-beam bridges constructed in the US and abroad. In addition, completed experimental research results and proposed AASHTO design procedures were evaluated by comparing their predictions to results from a finite element model. The model results showed that the proposed design procedures resulted in non-conservative load distribution factors and bending stresses for the Box-beam bridges, while there were little differences in the results for the T-beam bridges. Field performance of T-beam and Box-beam bridges was evaluated during an intensive field inspection program for selected bridges in West Virginia. Several bridges had cracks in their asphalt wearing surfaces at locations that corresponded to the location of the webs, which indicates that slip may be occurring between the webs and the flanges. The occurrence of slip would result in levels of structural safety lower than what has been assumed by the designers. Low stressing bar forces indicates that these bridge systems require more periodic maintenance than is currently being provided by local or state agencies. Examination of bridge costs showed that the mean superstructure costs of the T-beam and Box-beam bridges were higher than all other traditional timber bridge superstructure systems. There were no apparent span ranges or design changes that would result in a cost advantage for the bridge systems. Several additional research needs were identified if use of these bridge systems is pursued further. Overall, while the bridges are carrying vehicle traffic, there are several potentially serious issues that will affect their long-term ability to safely carry vehicle loads in a cost-effective manner. It appears that other, more traditional timber bridge systems are more attractive options than the stress-laminated T-beam and Box-beam bridges.

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Contents

	<i>Page</i>
Introduction	1
Objectives	2
Research Methods	3
Task 1: Review of Literature	5
Task 2: Evaluation of Completed Experimental and Analytical Studies	22
Task 3: Field Performance Characteristics and Trends for Bridges Constructed in the US and Abroad	65
Task 4: Additional Research Needs for Design Criteria and Bridge System Development	84
Task 5: Identify the Potential Use for T-Beam and Box-Beam Bridges	90
Summary and Conclusions	101
Appendices	
A. Compiled Field Data Taken During Inspection of Stress-Laminated T-Beam and Box-Beam Bridges in West Virginia.	A – 1
B. Examination of Design Procedures for Stressing Bar Anchorage Systems.	B – 1
C. Finite Element Model Development	C – 1
D. Proposed Bridge Design Criteria	D – 1
E. Analysis of Camp Arrowhead Bridge using Proposed AASHTO Methods and Finite Element Model	E – 1
F. Discussion of Prior Research: WVU CFC Report CFC-93-63	F – 1

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Introduction

Stress laminating is one of the newest techniques used in modern timber bridge construction. Stress-laminated deck superstructures consist of a series of lumber laminations that are placed edgewise and are transversely compressed with high-strength prestressing bars to create large structural assemblies. In contrast to longitudinal glued-laminated timber (glulam) deck assemblies and nail-laminated assemblies, which achieve load transfer among laminations by structural adhesives or mechanical fasteners, the load transfer between laminations in stress-laminated bridges is developed through compression and interlaminar friction. This interlaminar friction is created by the high-strength steel stressing elements typically used in prestressed concrete.

Findings from early research efforts and the funding of the U.S. Forest Service's Timber Bridge Initiative opened the door for the construction of many stress-laminated deck bridges in the United States. The early stress-laminated deck bridge designs had simple rectangular cross sections composed of longitudinal sawn lumber laminations with transverse prestressing (i.e., slab type systems). These designs proved relatively successful in short span applications and they were relatively cost effective. However, their moment of inertia was limited by the size of the available sawn lumber, which is generally 16 inches or less. Therefore, to achieve longer spans with stress-laminating technology, new concepts were needed.

To meet this need for longer spans, researchers first developed a stress-laminated cellular or Box-beam type of superstructure. The system consisted of stress-laminated top and bottom flanges connected with continuous webs. Flange material was assumed to be sawn lumber while the webs could be constructed of glulam beams, laminated-veneer lumber (LVL), parallel-strand

lumber (PSL), or other non-wood structural products. Box beam systems with fiber-reinforced webs were constructed next. Although early bridges built using this technology appeared to have acceptable structural behavior initially, the designs were not economically feasible due to increased costs for material, fabrication and labor. However, during further field testing, questions about the performance of the bridge systems arose. Also, current American Association of State Highway and Transportation Officials (AASHTO) specifications do not include design guides for Box-beam type stress-laminated bridges.

A design similar to the box type is one that uses a stress-laminated T or ribbed cross section. In this design, deep beams using glulam, LVL, or PSL can be stress-laminated to a relatively thin sawn lumber deck. The ribs formed by the deep beams significantly increase the stiffness of the bridge deck, thereby making longer spans possible. Researchers at West Virginia University constructed and tested experimental sections using both glulam and LVL webs. As with the Box-beam bridges, there have been questions related to the field performance and the cost effectiveness of these stress-laminated T-beam bridges, and AASHTO specifications are not available for them.

Additional research is needed to clarify the design, performance, and cost effectiveness of both of these newer types of stress-laminated bridge systems: stress-laminated T-beam and Box-beam bridge superstructures. This research is needed to provide input into the process for developing new timber bridge design procedures as well as to provide recommendations on the applicability of this bridge system for U.S. highways.

Objectives

Although the initial predictions for these stress-laminated T-beam and Box-beam bridge designs were encouraging, there are questions about their design procedures, their long-term performance, and their cost-effectiveness. Therefore, the objectives of this proposed research are to:

1. Conduct a literature review of all U.S. and international research and field performance information (published and unpublished);
2. Evaluate completed experimental and analytical laboratory studies to assess the adequacy, completeness, and merit of the work in addressing necessary design aspects for structural and serviceability bridge performance;
3. Identify and evaluate specific field performance characteristics and trends for bridges constructed in the U.S. and abroad;
4. Identify areas where additional research is necessary to fully develop design criteria for strength and serviceability performance; and
5. Identify the potential use for wood T-beam and Box-beam bridges relative to other commonly used wood bridge designs and define the most probable application guidelines for efficient construction and use of the bridge systems.

Research Methods

The following research tasks correspond to the previous research objectives.

Task 1: Literature Review

A comprehensive review of the literature was performed under this research task. This involved compiling published and unpublished reports on stress-laminated T-beam and Box-beam bridges. Both foreign and domestic research results were compiled.

Task 2: Evaluation of Completed Experimental and Analytical Studies

This step of the proposed research involved a review of previously-completed experimental and analytical work. Additional analytical studies were performed by the research team to validate the published analytical results. No experimental laboratory work was performed in this research. However, detailed finite-element studies were conducted to determine the validity of techniques that were used previously to predict the behavior of these bridges. These analytical techniques included variations of transformed section analyses and orthotropic finite element modeling. Data for these analytical studies were obtained from the Forest Products Laboratory (FPL) and from the published literature.

Task 3: Evaluate Field Performance Characteristics and Trends

Field performance data from the literature were reviewed to ascertain the past performance characteristic of constructed bridges. Such information typically consisted of bar force data from monitoring projects, data from static load tests, and intense visual inspections. Personnel from the FPL provided monitoring information for bridges monitored under FPL cooperative studies. Additional field performance data from other studies in the U.S. and abroad were reviewed as they became available.

Additional visual inspection of selected bridges was also an important part of the evaluation. A one-week-long trip to inspect several bridges in West Virginia was conducted in cooperation with personnel from the FPL. The bridges were visually inspected for signs of distress. Creep, interlaminar slip, performance of the wearing surface and other performance characteristics were evaluated.

Task 4: Identify Areas Where Additional Research Is Needed

Based on the results of the previous steps, the researchers were in a position to either recommend continuing with design provisions for T-beam and Box-beam bridges, based on existing performance data, or to suggest future directions for research on these bridges, which when completed would enable the complete development of design provisions. Also, there have been several changes in the design procedures of T-beam and Box-beam bridges at various points in

time since the designs were introduced. These results needed further examination to determine if additional studies are needed to resolve questions related to unsatisfactory behavior.

Task 5: Identify the Potential Use for T-Beam and Box-Beam Bridges

Many factors needed consideration before a valid statement regarding the application potential of the bridges could be made. Examples of some of the factors include material costs, fabrication cost, maintenance and longevity, aesthetics, and performance characteristics. To conduct this part of the study, the researchers focused on comparing cost data for existing T-beam and Box-beam bridges to the cost of other types of timber bridges. Various lumber price schemes were assumed in these analyses. These comparisons were made over various span and design load ranges. Using the results of these comparisons, recommendations were made as to when a particular bridge design is applicable.

The following sections of the report address each of the research tasks as introduced here. Additional details on the procedures employed in the research are provided in the following sections.